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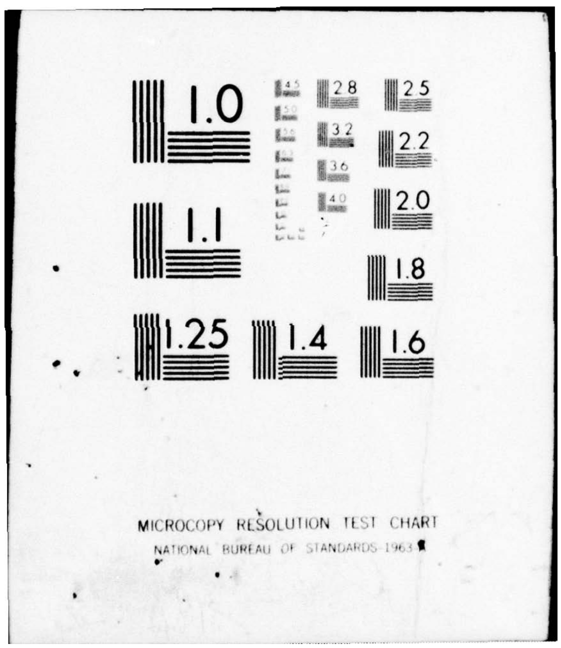
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# EVALUATION OF THREE TYPES OF TECHNICAL DATA FOR TROUBLESHOOTING: RESULTS AND PROJECT SUMMARY


By

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This final report was submitted by Systems Research Laboratories, Incorporated, 2800 Indian Ripple Road, Dayton, Ohio 45440, under contract F33615-75-C5103, project 1194, with Advanced Systems Division, Air Force Human Resources Laboratory (AFSC), Wright-Patterson Air Force Base, Ohio 45433. Dr. Donald L. Thomas, Personnel and Training Requirements Branch, was the contract monitor.

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This technical report has been reviewed and is approved.

GORDON A. ECKSTRAND, Director
Advanced Systems Division

Approved for publication.

DAN D. FULGHAM, Colonel, USAF
Commander

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fully proceduralized troubleshooting aids
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job performance tests
logic tree troubleshooting aids
technical orders
troubleshooting

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes a project to evaluate the effectiveness of three types of technical data for troubleshooting, fully proceduralized troubleshooting aids (FPTA), logic tree troubleshooting aids (LTTA), and technical orders (TOs). In the project, FPTAs and LTTAs, were developed for two moderately complex electronic systems, the AN/APN-147 and AN/ASN-35. The effectiveness of the technical data and the existing TOs for the systems were then evaluated by determining which provided the best support for technicians troubleshooting the systems. This was accomplished by inserting faults into the equipment and having a technician troubleshoot the system using one of the three types of data. Job performance tests were used to measure the performance of the technicians. Technicians with three levels of experience participated in the study. They were: apprentice technicians → next page

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with no field experience, experienced technicians with less than six months experience on the systems, and experienced technicians with more than six months experience on the systems. The results indicate that: (1) apprentice technicians are able to troubleshoot more effectively when using FPTAs than when using LTTAs; (2) apprentice technicians troubleshoot more effectively when using FPTAs or LTTAs than when using TOs, (3) apprentice technicians using FPTAs are able to troubleshoot as effectively as experienced technicians using TOs, and (4) fewer parts are replaced unnecessarily when FPTAs or LTTAs are used than when TOs are used.

## SUMMARY


### PURPOSE

The purpose of the project described in this report was to conduct an evaluation comparing fully proceduralized troubleshooting aids (FPTAs), logic tree troubleshooting aids (LTTAs), and technical orders (TOs) in terms of:

1. The costs involved in developing each type of aid.
2. The technical accuracy of each type of data.
3. The effectiveness of each type of data for supporting maintenance personnel of varying experience levels in performing troubleshooting tasks.

### METHOD

Cost comparison: The available data on costs to produce each of the three types of technical data were obtained from FPTA and LTTA contractors, and from the Air Force Logistic Centers responsible for TO procurement. Due to differences in coverage, developer experience, data base and types of systems for which the technical data were developed, difficulty was experienced in arriving at a single measure which would permit a meaningful comparison of the three document types. The approach selected was to base the analysis on the cost to produce a page unit. A page unit was defined as a standard 8 1/2- by 11-inch format. Use of this standard made it necessary to convert the 4- by 8-inch page format used in the LTTA checkout procedures for organizational level maintenance into the standard page unit. No other page conversions were required.

Technical accuracy: Review of worldwide Air Force maintenance actions was undertaken to provide identification of maintenance areas which could serve as representative candidates for development of troubleshooting test problems. Thirty specific troubleshooting test problems were selected and distributed throughout the AN/APN-147 (radar) and AN/ASN-35 (computer) systems of the C-141A aircraft. Each problem was inserted into working system equipment. The effects on system operation were identified and a systematic evaluation of the accuracy of the technical documentation types in supporting the isolation of the faults was undertaken. Records were maintained on the errors found in the data and on whether the procedure led to isolation of the problem. Those faults which could be successfully isolated by each of the three types of technical data were retained for consideration as a test problem in the field data collection phase.

Experimental evaluation of effectiveness of each technical data type: Three experience levels of Air Force technicians in the Avionics Inertial and Radar Navigational Systems Specialty (AFSC 328X4) served

as subjects. The experience levels were: recent graduates of the technical training course (no field experience); technicians with six months or less experience; and technicians with more than six months experience. Eighteen technicians at each experience level were used as subjects. A determination was made that it would not be appropriate to test the no-experience group on technical orders. This decision made it necessary to use two different, but similar, experimental designs. Both designs involved repeated measures on subjects. In the first design, the no-experience group was tested using two types of data, FPTAs and LTTAs. In the second design, the two experienced groups of subjects were tested using all three types of data. Data collection was accomplished at Keesler Technical Training Center and at three Military Airlift Command bases: McChord, Travis, and McGuire.

## RESULTS

The cost comparison, primarily due to the fact that sufficient comparable data could not be assembled, produced inconclusive results. However, the available data did suggest that the costs of developing fully proceduralized troubleshooting aids in a newly developed system where all support data would also have to be generated may not be much different from the costs incurred in technical order development.

Errors in technical accuracy were found in both the FPTA and LTTA. The errors discovered vary in their impact on performance from negligible to completely disruptive. However, no accuracy errors were found that were considered beyond solution. Increased emphasis on quality control would eliminate most of the accuracy errors found.

The results of the experimental evaluation clearly demonstrate that the use of proceduralized troubleshooting aids resulted in significantly better troubleshooting than the use of the TO. This finding held for two of the three measures: proportion of problems solved and spare parts consumed. For the third measure, time to troubleshoot, the use of TOs resulted in better performance at the organizational level but not at the intermediate level of maintenance.

In comparing the FPTA against the LTTA, the FPTA was superior for the no-experience group on all measures. For experienced technicians, use of the FPTA resulted in slightly better performance on all measures except time to troubleshoot at the organizational level.

In addition to the objective performance data, subjective opinion data of the technicians provided unqualified support for the use of the FPTA as the most favored of the three types of technical documentation.

The findings of this research effort support the following recommendations:

1. Consideration should be given to development of FPTAs or LTTAs for new procurements of technical data for troubleshooting (whether for new or existing systems). It is especially important that these types of data be considered for intermediate level maintenance where the benefits are likely to be greatest.

2. Proceduralized troubleshooting data (FPTA, LTTA, or hybrid) should be developed for a modern Air Force system for operational use to provide an opportunity to study the problems associated with using this type of data in an operational setting.

3. Strong emphasis should be placed on accuracy evaluation.

4. Additional analyses of the costs and cost benefits of FPTAs and LTTAs should be made.

5. The potential of FPTAs and LTTAs for reducing training costs should be evaluated.

6. Strong consideration should be given to modification of the LTTA format to include more of the proceduralization material contained in the FPTA.

This report is in three volumes: This volume presents a summary of the project and the results. Volume II presents a detailed description of the experimental procedures used in the study. Volume III presents the test administrator's guide and the job performance tests.

# PREFACE

This study was initiated by the Advanced Systems Division, Air Force Human Resources Laboratory, (AFHRL) Wright-Patterson Air Force Base, Ohio. The research was performed by Systems Research Laboratories, Inc., Dayton, Ohio, under Contract F33615-75-C-5103, with Dr. Norman R. Potter as principal investigator.

This project was conducted with the guidance of a steering committee composed of representatives of the participating agencies. Appreciation is expressed to the following members of the committee: Mr. Robert Welsh, Lt. Colonel Willie Sylva, and Capt. Autry Talley, Headquarters, United States Air Force; Dr. Donald Meyer, Headquarters, Air Training Command; Mr. James McGrath and Mr. Mat Gutieney, Air Force Logistics Command, and SMSGT Clarence Padgett, Headquarters, Military Airlift Command.

The authors wish to acknowledge the contributions of the members of the Systems Research Laboratories field evaluation team, Mr. Ned H. Kearns, Mr. P. Richard Hubbert, Mr. James V. Landolfi, and Mr. Daniel L. Rice. Without their efforts and dedication to the data collection effort, this project could not have been accomplished. Further an appreciation must be expressed to MSGT Bobby Spaulding, AFHRL, for his guidance and support throughout the field data collection effort, and Wing Commander Christopher J. Hyatt, Aeronautical Systems Division and to Mr. John J. Klesch, AFHRL, for their guidance and knowledgeable consultation throughout the project.

Appreciation is extended to those personnel at each of the bases visited who made our task possible to accomplish. The individuals named below cooperated in a particularly noteworthy fashion in providing assistance to the field evaluation team:

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McChord Air Force Base

MSgt Clarence D. Eamons
TSGT L. D. Kaiser

TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd)

# LIST OF ILLUSTRATIONS

## LIST OF ILLUSTRATIONS (cont'd)

## LIST OF ILLUSTRATIONS (cont'd)

## LIST OF TABLES

LIST OF TABLES (cont'd)

## EVALUATION OF THREE TYPES OF TECHNICAL DATA FOR TROUBLESHOOTING: RESULTS AND PROJECT SUMMARY

### Section I

### INTRODUCTION

The steadily increasing costs of maintaining Air Force operational systems, combined with current austerity programs, make it essential that new ways of reducing maintenance costs be identified and implemented. One way of reducing costs is to improve the effectiveness of maintenance personnel, and thereby reduce manpower requirements. Manpower costs for maintenance personnel presently account for 15 percent of the Air Force budget. Thus, the area of maintenance manpower costs offers the potential for significant cost savings.

One approach which has significant potential for improving the efficiency of maintenance personnel and reducing costs is the development of improved types of technical data for use by maintenance personnel. Many types of improved technical data have been proposed for use by Air Force and other Department of Defense agencies. These include data such as:

- o Maintenance Dependency Charts and Schematic Block Diagrams (Mil-M-38799)
- o Functionally Oriented Maintenance Manuals (MIL-M-24100B)
- o Logic Tree Troubleshooting Aids (MIL-M-38800A)
- o Fully proceduralized Troubleshooting Aids (AFHRL-TR-73-43(I))

The new types of data represent attempts to improve the content and method of presenting information and directions for technicians to use. Proponents of the new types of data usually claim that this type of data has significant advantages over standard technical orders and other types of improved technical data. However, there is usually little empirical data to support these claims. The potential financial impact of implementing new types of technical data makes it essential that decision makers have valid information available on the benefits of each.

The project reported in this technical report was designed to provide empirical data on the relative effectiveness for supporting troubleshooting activities of two of the new types of data in comparison to standard technical orders (TOs). The two new types of data are Fully Proceduralized Troubleshooting Aids (FPTAs) and Logic Tree

Troubleshooting Aids (LTTAs). Both FPTAs and LTTAs provide step-by-step procedures for troubleshooting. They differ in the format in which the procedures are presented, the level of detail, and the procedures used to develop the data.

Proponents of both FPTAs and LTTAs claim that their type of data has significant advantages over standard technical orders. They claim that the use of FPTAs and LTTAs will result in:

1. More efficient maintenance by:

   a. Reducing the time required for troubleshooting.

   b. Reducing utilization of spare parts (due to fewer removals of good parts).

2. More efficient use of personnel by:

   a. Permitting less experienced technicians to troubleshoot effectively (making it possible for them to be productive earlier in their enlistments).

   b. Facilitating the transfer of personnel experienced on one system to an unfamiliar system.

   c. Reducing training requirements.

Proponents of FPTAs believe that the more thorough analysis used in the development of FPTAs produces data of a much better quality. Consequently, they believe that FPTAs will achieve all of the above advantages with a greater degree of success. They also believe that the rigidly specified FPTA development, validation, and verification procedures will produce data that are technically more accurate (have fewer errors) and more complete.[1]

Proponents of LTTAs believe that this type of data can support troubleshooting tasks as effectively as FPTAs at much less cost. They believe that the rigid development procedures specified for FPTA development are not necessary to produce high quality data and that significant economics can be obtained by allowing the contractor to have more freedom in the development process. They also believe that the high level of detail provided in the FPTA is not necessary except for very inexperienced personnel. They do not feel that the additional cost incurred in providing the detail (in terms of development cost and extra pages to produce and maintain) are justified for the relatively few technicians who require this level of detail.

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[1]The FPTA technology was developed by the Air Force Human Resources Laboratory as a result of a 15 year program to improve technical data for maintenance. See Foley (1973) for a description of the research program and a more complete description of the benefits.

As indicated above, the use of proceduralized data for troubleshooting could have a significant impact on the cost of Air Force maintenance. Theoretically, a proceduralized approach permits fault isolation in a shorter period of time in that it eliminates false starts and blind alleys in the troubleshooting process. This saving in troubleshooting and repair time can result in two separate benefits to the Air Force, more productive utilization of the maintenance technician, and more in-commission (or on-line) time for Air Force equipment and systems. An additional benefit foreseen from the increase in troubleshooting efficiency is that the Air Force can reduce its spare parts stock inventory requirements. The present trial-and-error method of troubleshooting (question, remove, replace, and test) contributes in many instances to unnecessary replacement of good parts and components. The number of parts unnecessarily used in repair activities can be significantly reduced and possibly largely eradicated through proceduralized approaches to troubleshooting.

The use of proceduralized troubleshooting has significant promise for improving the efficient use of maintenance personnel. This is due primarily to the fact that extensive knowledge of the system is not needed to effectively troubleshoot. Theoretically, then, it should be possible for a technician with limited experience to troubleshoot effectively using proceduralized data. Also, it should be possible for a technician with experience on one system to troubleshoot a similar but unfamiliar system. The implications for savings in both training costs, and in manpower costs through longer productive utilization of the airman in his initial enlistment period, and in the transition of experienced technicians between systems are highly significant.

The potential impact of proceduralized troubleshooting approaches on training deserves special comment. In the present technical training concept, large blocks of training time must be devoted to the presentation of theory. Frequently, the theory is presented at the expense of direct hands-on practice. Thus, the technician arriving at an operational assignment from technical training is not capable of assuming maintenance duties. He must be placed in additional training in his unit of assignment to obtain the practical experience required to permit him to work with the equipment. The training used with proceduralized technical documentation, as a rule, has emphasized hands-on practice to obtain equipment familiarity. Thus, an airman trained in such a manner is able to function in a productive capacity much earlier in his term of enlistment than is true with present training methods. With proceduralized documentation, the technician does not require a knowledge of the theory underlying the operating system to maintain it, and this elimination represents a savings in both training time and costs. Each technician has a longer productive period in his first enlistment. Further, this approach permits a more intensive selection process for additional training to take place;

thus, permitting the Air Force, to a greater extent than is presently true, to invest its training monies on those technicians showing greatest promise for return of investment.

The present project was designed to collect data relative to ability of FPTAs and LTTAs to improve maintenance efficiency and their effectiveness for improving the performance of technicians with varying levels of experience. The impact of FPTAs and LTTAs on training requirements was not directly assessed in this project. However, it was possible to obtain a limited amount of data relative to the potential of the FPTAs and LTTAs for facilitating transfer of technicians to new systems. These data are summarized and discussed separately in Appendix C.

## STATEMENT OF THE PROBLEM

The purpose of the project described in this report was to conduct an evaluation comparing fully proceduralized troubleshooting aids, logic tree troubleshooting aids, and technical orders in terms of:

1. The cost to develop each type of data.

2. The technical accuracy of each type of data.

3. The effectiveness of each type of data for supporting maintenance personnel of varying levels performing troubleshooting tasks.

Effectiveness of each type of technical data was evaluated through accomplishment of a research design which permitted the following questions to be addressed:

1. Does quality of performance with the three types of documentation depend upon experience level of the technician?

2. Does FPTA performance differ from LTTA performance? Are both FPTA and LTTA performance different from TO performance?

3. Is there an interaction between type of technical data and level of experience? If so, what is the nature of the interaction?

4. Does performance with the three types of technical documentation differ for organizational and intermediate level maintenance troubleshooting?

5. Is there a statistical interaction between level of maintenance troubleshooting and level of experience? If so, what is the nature of the interaction?

6. Is there a statistical interaction between FPTA or LTTA technical data and level of maintenance troubleshooting? If so what is the nature of the interaction?

7. Is there an interaction among types of technical documentation, experience level and level of maintenance troubleshooting? If so, what is the nature of the interaction?

GENERAL APPROACH

To evaluate the three types of data, it was necessary to first develop FPTAs and LTTAs for a test system. FPTAs and LTTAs were developed under contract for the AN/APN-147 doppler radar and AN/ASN-35 computer as configured in the C-141. FPTAs and LTTAs were developed to provide procedures for all routine troubleshooting tasks performed at the organizational and intermediate levels of maintenance. The development of the aids and reasons for selecting the test systems are described in Section II of this volume.

An analysis of the comparative costs of developing the three types of data was made by collecting data on the costs of preparing the FPTAs and LTTAs developed in this study. The results of this analysis are summarized in Section IV.

The analysis of the accuracy of the FPTAs and LTTAs was made by selecting representative faults which occur in the systems and using each type of data to isolate the fault. The analysis considered whether the data did in fact lead to successful isolation of the problem and the number, type, and seriousness of errors identified in the data. The results of this analysis are given in Section II of this volume of the report.

The major emphasis of the study was directed toward determining the effectiveness of each type of data for supporting the technician performing troubleshooting tasks. There are several approaches which may be taken in determining the effectiveness of technical data for supporting troubleshooting tasks. The most valid technique would be to introduce the data into the operational environment for use in regular troubleshooting tasks in support of the unit's mission. However, this approach usually is not feasible since the adequacy of the data is unproven and its use may interfere with the mission of the test unit. This approach is also handicapped by the fact that it is very difficult to obtain adequate measures of maintenance effectiveness in an operational environment. Due to the interference of many extraneous factors, it is not possible to obtain accurate data on important factors such as rate of successful completion of the troubleshooting task, time to complete the task, and errors made. As a result, it is usually necessary to rely on the opinions of or ratings by technicians, supervisors, and other observers as measures of

effectiveness in the operational setting. This type of data is extremely subject to bias and easily influenced by outside factors. Therefore, this approach was considered unacceptable for this project and was not used.

A second approach is to simulate the maintenance environment by having technicians perform maintenance tasks using each type of data under controlled conditions. Performance tests are used to measure the technicians' tasks. For each test, the technician is told to troubleshoot the system or component of the system using the data being evaluated. A trained observer monitors his performance and records errors made, problems encountered in using the data, whether the task is correctly accomplished, and the time required to complete the task. This technique closely simulates the maintenance environment while controlling most of the extraneous factors which affect performance. However, the technique has several disadvantages. It requires that actual prime equipment be made available and dedicated to the project. For an operational system, such equipment is often very difficult to obtain. It requires the time of several technicians to complete a number of maintenance tasks. Thus, a significant number of man-hours are required to obtain an adequate sample of performance. Finally, a trained observer is required to monitor the performance of the technician. In most cases, monitoring must be on a one-to-one basis. Consequently, a significant amount of observer time is required. In summary, this approach should provide the most valid data but it is very time consuming and costly.

A third approach which has been used in some studies is to attempt to simulate the maintenance task through use of paper-and-pencil tests. In this approach, the technician is given the technical data being evaluated and information on the results that would be obtained at each test point if the prescribed test were actually performed. The technician uses the technical data to determine what checks should be made and refers to the information package for the test results. The technician's performance is evaluated on whether he successfully identifies the fault. This approach has the advantages of not requiring the prime equipment, requiring a relatively small amount of the technicians's time, and being suitable for group administration. However, this approach has the very significant disadvantage of not adequately simulating the maintenance environment. There are several factors which influence whether a technician is able to use a manual to troubleshoot besides being able to follow a sequence of checks. For example, does the technical data clearly tell the technician where a test point is located? If he cannot find the test point, he cannot make the check. Thus, it is very possible that a technician may be able to do well on a paper-and-pencil test and still not be able to solve the problem using the test data on the actual equipment. Thus, the validity of this approach is questionable.

Although the performance test approach is significantly more expensive and time consuming, it was believed that the validity and other benefits of the approach justified the cost and time. This approach was used. The procedures and results are described in Sections V and VI. A detailed description of the experimental procedures utilized is presented in AFHRL-TR-76-74(II).

## TEST FACILITIES

As indicated above, the performance test approach requires dedicated access to the prime equipment for extensive periods of time. It was realized that it would not be possible to obtain sufficient access to test benches at operational bases without causing an unacceptable degree of interference with their mission. Further mission requirements usually create an unacceptable degree of interference with the test schedule. To ensure adequate access to the equipment at all test locations, a 40-foot Air Force van was equipped with bench mockups of the AN/APN-147 and AN/ASN-35 to provide a transportable test facility. It was also recognized that it would be extremely difficult to obtain adequate access to C-141 aircraft for use with the organizational level tests. Thus, a mockup of the C-141 cockpit and the avionics equipment bays of the C-141 was developed and installed in the test van. The cockpit mockup provided a means of simulating the flightline troubleshooting tasks wihtout requiring access to an aircraft. It consists of mockups of all instrument panels in the cockpit. All AN/APN-147 and AN/ASN-35 components were "live" and functioned in the same manner as the actual cockpit. All other components on the instrument panels were represented by photographs. Figure 1 is a photograph of the exterior of the van. Figure 2 is a view of the cockpit mockup area inside the van. Figures 3 and 4 are views of the bench mockups contained in the van.

## CONTENTS OF THIS REPORT

The report is complete in three volumes. This volume (AFHRL-TR-76-74 (I)) provides a summary of the entire project. The remaining volumes provide detailed information on various portions of the study for those requiring additional detailed information for analysis or replication. The two additional volumes are:

Volume II, Treatment Plan. This volume provides a detailed description of the experimental procedures used in the experimental evaluation portion of the project.

Volume III, Test Administrator's Guide. This volume provides instructions and guidance for administering the job performance tests used to measure performance of technicians using FPTAs, LTTAs, and TOs.

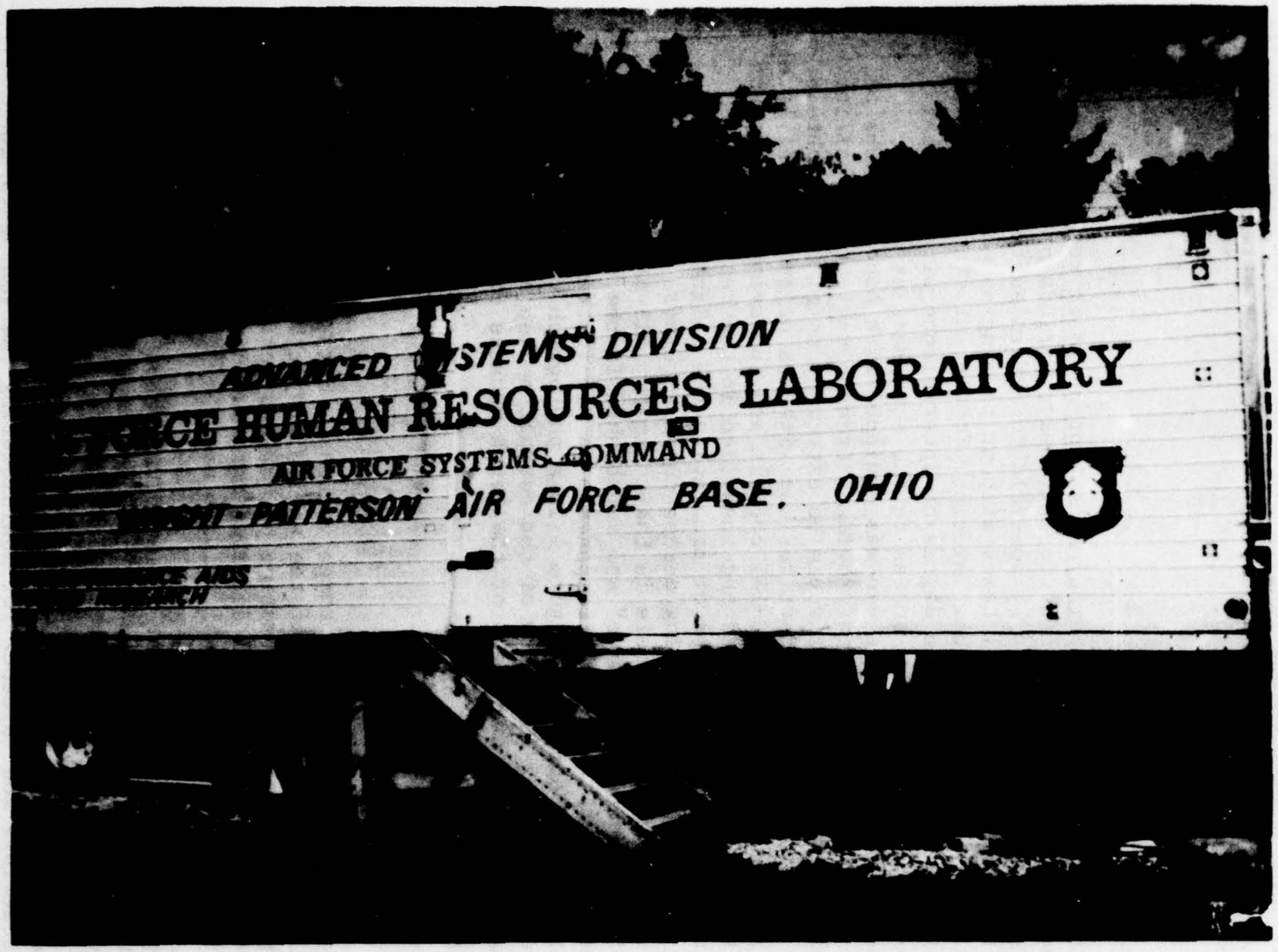



Figure 1. Exterior View of Air Force Van Used to House the C-141A Cockpit Mockup and the Radar and Computer Maintenance Benches used in Field Data Collection

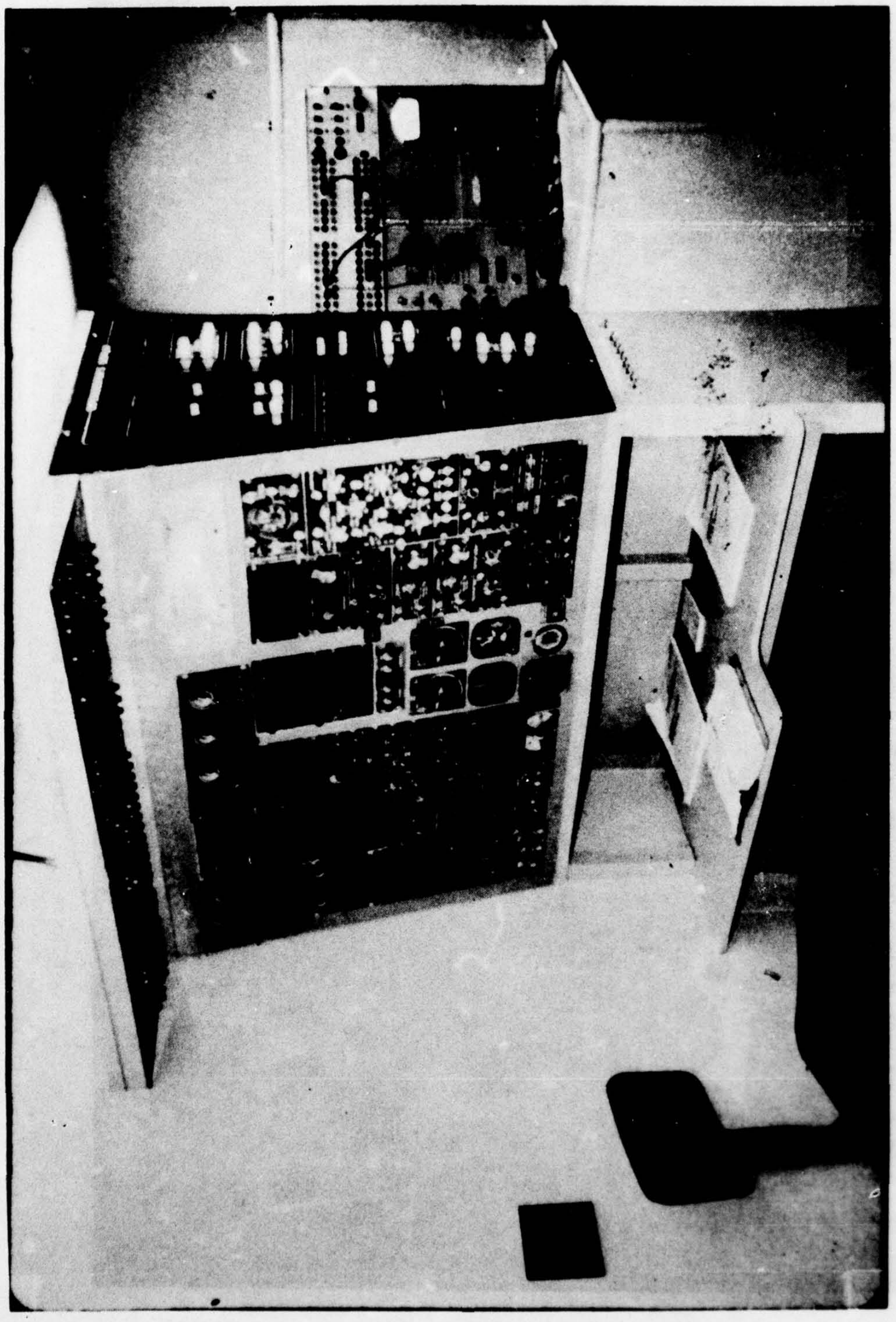


Figure 2. View of the Navigator Panel of the C-141A Mockup

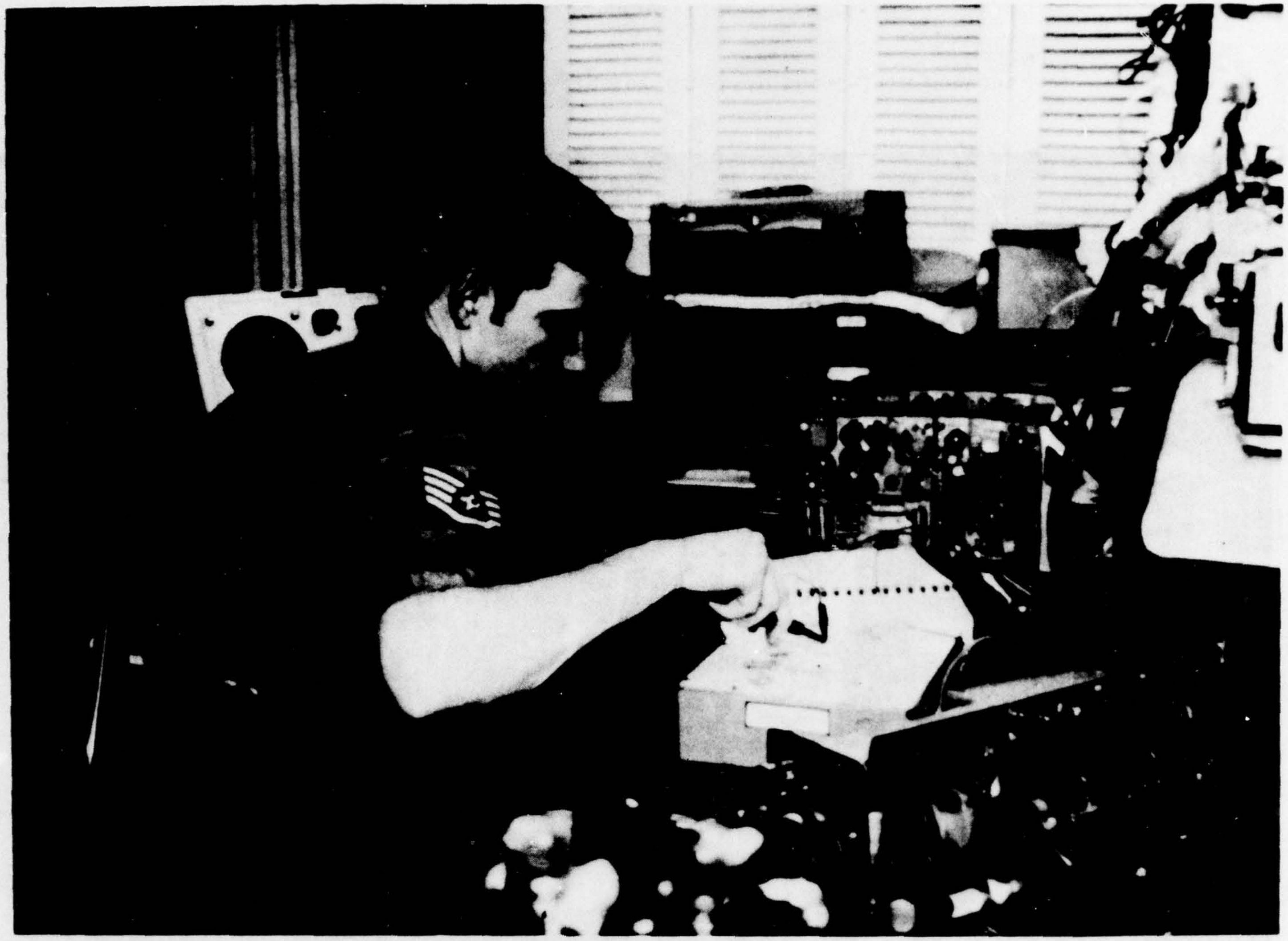


Figure 3. View of the Radar Maintenance Bench

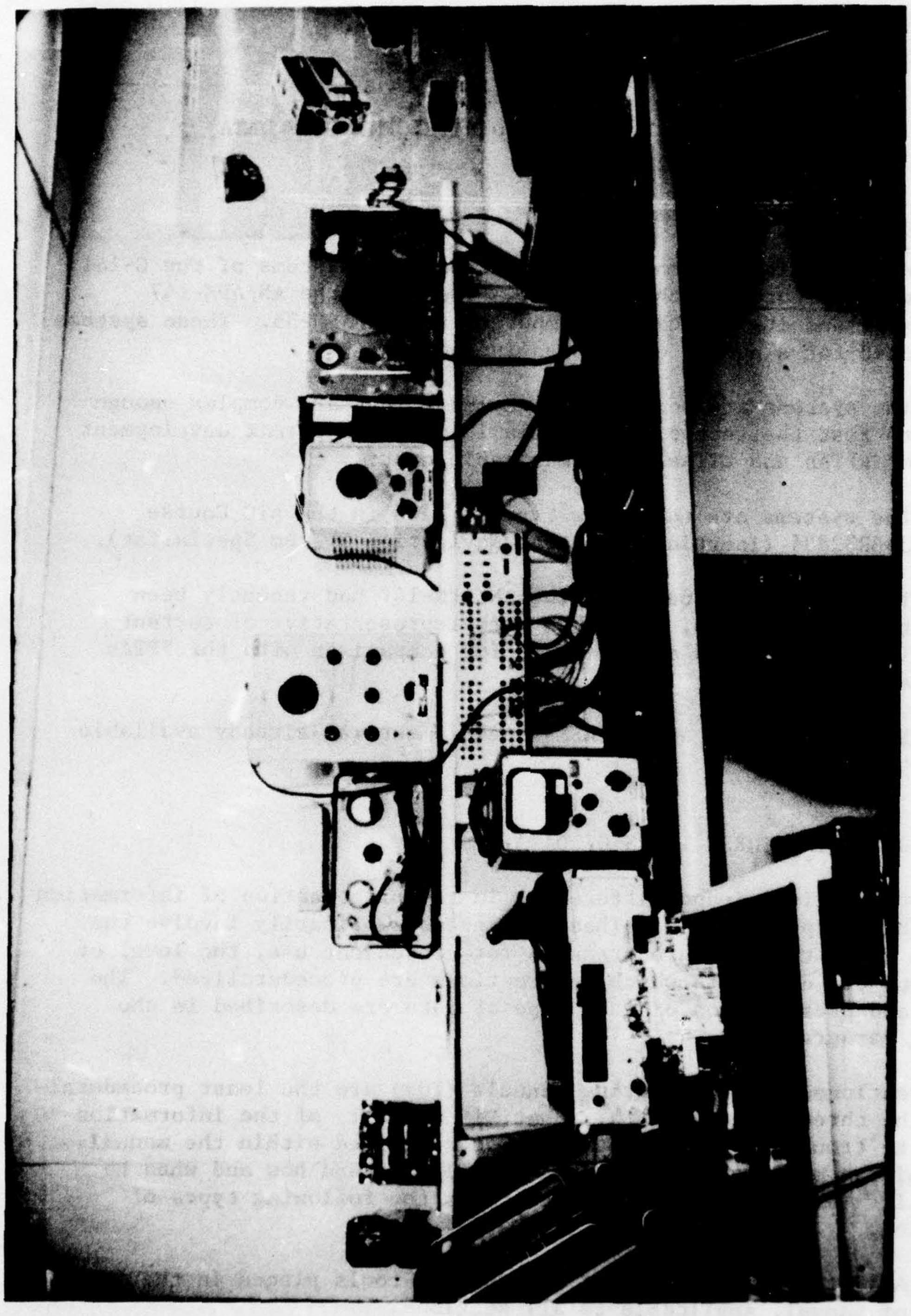


Figure 4. View of the Computer Maintenance Bench

## Section II

## SELECTION OF TEST SYSTEM AND DEVELOPMENT OF DATA

### SELECTION OF THE TEST SYSTEM

As indicated in Section I, two electronic subsystems of the C-141 aircraft were selected as the test bed. These are the AN/APN-147 doppler radar and its associated computer, the AN/ASN-35. These systems were selected for a number of reasons including:

1. The systems are moderately complex. They are complex enough to test the technology and small enough to permit development of FPTAs and LTTAs at a reasonable cost.

2. The systems are taught as typical sets in the ATC Course 3ABR32834 (Inertial and Radar Navigation System Specialist).

3. The technical orders for the AN/APN-147 had recently been rewritten. Thus, these TOs were representative of current TOs and provided a good basis for comparison with the FPTAs and LTTAs.

4. Some AN/APN-147 and AN/ASN-35 equipment was already available to AFHRL.

### DESCRIPTION OF THE THREE TYPES OF DATA

There are significant differences in the presentation of information for the three types of data. These differences primarily involve the extent to which the data are arranged for convenient use, the level of detail, and the degree to which instructions are proceduralized. The contents and presentation of each type of data are described in the following paragraphs.

Conventional troubleshooting manuals (TOs) are the least proceduralized of the three types of data. Most, if not all, of the information required to troubleshoot the equipment is contained within the manual. The technician must decide what data he will use and how and when he will use it. The manual generally contains the following types of information.

1. A list of test equipment and special tools placed in the front of manual, applicable to all sections.

2. Major sections covering equipment units of the system. Each of the sections contains several different types of illustrations such as:

   a. photographs or line drawings identifying modules and major and minor test points.

   b. a troubleshooting chart containing a checkout procedure (somewhat proceduralized) and a symptom-cause table that indicates probable malfunctions when a checkout step is failed.

   c. voltage and resistance diagrams.

   d. voltage waveforms.

   e. block diagrams.

   f. schematic diagrams.

   g. wiring diagrams.

3. A functional description of the equipment and detailed circuit description.

The troubleshooting procedure will generally isolate the malfunction to a particular stage and then refer the technician to the appropriate diagram or illustration. The manuals are prepared assuming that the technician has experience and training in the use of test equipment, in locating most parts within the equipment, and in interpreting schematic diagrams. Figures 5 and 6 contain samples of TO pages. Figure 5 is a page from the checkout section of the TO; Figure 6 contains a page from a symptom-cause table.

The logic tree troubleshooting aids are somewhat more proceduralized than conventional manuals in that specific instructions are provided both in the checkout procedure and in the troubleshooting procedure. The troubleshooting procedures begin at the step in the checkout procedure that produced the failure. Figure 7 contains a checkout procedure with a selected trouble outlined. LTTAs contain a cross-reference from failed checkout procedure to troubleshooting procedure (Figure 8). This index may either reference the proper troubleshooting tree or pinpoint a fault directly. The troubleshooting logic trees (Figure 9) give exact procedures to be performed and ask questions about results obtained while monitoring voltage, waveforms, and/or resistances at specific points in the suspect circuit. The yes or no answer to these questions provides the logic in the fault isolation procedure. Each path ends with instructions to replace a faulty component. Sometimes a path will first identify the faulty stage or assembly and will direct the technician to perform the checkout procedure for that stage of assembly.

T.O. 5N1-3-8-2

6-8. Set test harness controls as follows:

a. HEADING TRACK SIMULATOR switch to INT.

b. Deleted

c. Deleted

d. Set audio oscillator to 12,240 ± 10 Hz at 10V P/P (3VRMS).

e. 26VAC EXC switch to INT.

f. LAND/SEA/SS switch to SEA.

g. DRIFT ANGLE switch to OUT.

h. HEADING TRACK SIMULATOR to 000.0 degrees.

i. COMPUTER REFERENCE TRACK switch to IN.

6-9. Set control indicator (C-3748A, etc) as follows:

a. OFF/MAN/AUTO switch to OFF.

b. DISTANCE TO GO, STAGE I to 100 NM.

c. DISTANCE CROSS TRACK to 00.0NM RIGHT.

d. DESIRED TRACK ANGLE, STAGE I to 000.0°.

e. Stage switch to STAGE I ACTIVE.

6-10. Set control indicator auxiliary (C3749A, etc.) as follows:

a. NAV/DROP switch to NAV.

b. DISTANCE CROSS TRACK to 00.0NM RIGHT.

c. Selector switch to AUXILIARY STAGE I, MAIN CROSS TRACK STAGE II.

6-11. Turn power on and allow time for system and test equipment warmup.

6-12. TEST PROCEDURE.

6-13. Set control indicator OFF/MAN/AUTO switch to MAN.

a. DISTANCE TO GO counter should decrease.

b. DISTANCE CROSS TRACK counter should not change.

c. Indicator-Multiple (1D939A) OFF flag is not in view.

d. Indicator pointer is at 0°.

e. Indicator cross track bar is at center.

f. Indicator DISTANCE TO GO counter is decreasing and reads the same as DISTANCE TO GO counter on control indicator.

6-14. Set test harness HEADING SIMULATOR to 090.0°.

a. Control indicator DISTANCE TO GO counter does not change.

b. Control indicator auxiliary DISTANCE CROSS TRACK counter increases RIGHT.

c. Indicator pointer should be at 90°.

d. Indicator cross track bar slowly moving left.

e. Indicator DISTANCE TO GO counter does not change.

6-15. Set test harness HEADING SIMULATOR to 180.0°.

a. Control indicator DISTANCE TO GO counter should increase.

b. Control indicator auxiliary DISTANCE CROSS TRACK counter should not change.

c. Indicator pointer should be at 180°.

d. Indicator cross track bar does not change (not necessarily positioned at center of scale).

6-2 Change 14

Figure 5. Example Page from TO Field Maintenance Instructions for Computer Set, Navigational

| Step | Test Point | Test Equipment | Control Settings and Instructions | Normal Indication | If Indication Is Normal | If Indication Is Abnormal |
|---|---|---|---|---|---|---|
| 8 | Terminals A-13, A-14, A-11, andA-12 on test harness | Audio oscillator and AVO-8 | With the audio oscillator as in step 7 and the heading track simulator set to zero, set the DESIRED TRACK ANGLE counter between 000.0 and 180.0 degrees. Connect the frequency meter across test points A-11 and A-12 (common) | DISTANCE CROSS TRACK counter reading increases LEFT or decreases RIGHT. | Proceed to step 9. | If there is no "left" pulse input at A-11 and A-12, check for faulty connections or fault in computer. Check pawl and star wheel. Check gear train for signs of jamming. |
| 9 | Terminals A-13, A-14, A-10 A-12 on test harness | Audio oscillator and AVO-8 | With the audio oscillator and the heading track simulator set as in step 8, set the DESIRED TRACK ANGLE counter between 180° and 359.9 degrees. Connect the frequency meter across test points A-10 and A-12. | DISTANCE CROSS TRACK counter reading decreases LEFT or increases RIGHT. | Proceed to step 10. | If there is no "right" pulse input at A-10 and A-12, check for faulty connections or fault in computer. Check pawl and star wheel. Replace relay K5404 if faulty. |
| 10 | Terminals A-13, A-14, D-6 and D-7 on test harness | Audio oscillator and AVO-8 | With the audio oscillator and the heading track simulator as in step 8, set the DESIRED TRACK ANGLE (STAGE I and STAGE II) counters to 45°. Turn the AUTO-MAN switch to OFF. Set the DISTANCE TO GO STAGE I counter at 50 miles and the DISTANCE CROSS TRACK counter at 50 miles LEFT. Turn the AUTO-MAN switch to MAN. | Readings on both counters should remain identical while decreasing from 50 to 0 miles. | Repeat the step, but using the DISTANCE TO GO STAGE II counter. | a. If readings differ, check for 0° actual track input from the heading track simulator at test points D-6 and D-7. If voltage is other than zero, simulator is faulty. b. If voltage is zero, repeat the step, but using the DISTANCE TO GO STAGE II counter. If readings of the DISTANCE CROSS TRACK and DISTANCE TO GO counters correspond for stage I but not for stage II, the STAGE II DISTANCE TO GO counter is faulty. |

Figure 8-2. Table of Control-Indicator Trouble Analysis (Sheet 3 of 6)



Figure 6. Example Page from TO Field Maintenance Instructions for Computer Set, Navigational (continued on page 27)

Section VIII    T.O. 5N1-3-8-2

| Step | Test Point | Test Equipment | Control Settings and Instructions | Normal Indication | If Indication Is Normal | If Indication Is Abnormal |
|---|---|---|---|---|---|---|
| 10 (cont) | | | | | | If they correspond for stage II but not for stage I, the STAGE I DISTANCE TO GO counter is faulty. If they do not correspond for either stage, the DISTANCE CROSS TRACK counter is faulty. |
| 11 | Terminals C-4, C-5, B-18, B-19 on test harness | Electronic voltmeter ME-6( )/U | Connect meter to C-4 and C-5. Set the DISTANCE CROSS TRACK counter to 3 miles RIGHT or LEFT. Adjust R124 in the computer to obtain a meter reading of ±150 mv. Reset the counter to 15 miles RIGHT or LEFT, and readjust R124 until meter again reads ±150 mv. | When DISTANCE CROSS TRACK counter reads LEFT, the voltage at C-4 is positive and at C-5 is negative. When the counter reads RIGHT, the polarities are reversed. | Cross track d-c potentiometer R5401 is functioning correctly. | Check for 12 volts dc at B-19 and B-18 (gnd). If voltage absent, apply 12 volts dc to B-19 and B-18, and repeat the step. If the specified normal indication is obtained, the fault is in the computer. If the normal indication is not obtained, replace R5401. Check diode limiters CR5404 and CR5405 for short circuit; replace if defective. |

Figure 8-2. Table of Control-Indicator Trouble Analysis (Sheet 4 of 6)

8-6

Figure 6. Example Page from TO Field Maintenance Instructions for Computer Set, Navigational (concluded)

3. On air navigation multiple indicator, observe that OFF flag is not visible.

4. On navigational computer, observe that blower is operating.

5. On test harness, set 115V AC switch to OFF.

6. On control indicator, observe that OFF indicator is lit.

7. On test harness, set 115V AC switch to ON.

8. On test harness, observe that 26 Vac power is present at test points B12 (hot) and E6(return).

9. On test harness, adjust HEADING TRACK SIMULATOR readout slightly if necessary for precise null (minimum ac voltage) between test points D6 and D7. Use ME-6( )/U Electronic Voltmeter for null indication.

3-5. DISTANCE TO GO SENSE AND READOUT

1. On control indicator, observe that STAGE I DISTANCE TO GO readout is decreasing.

2. On air navigation multiple indicator, observe that DISTANCE TO GO readout is decreasing.

3. On air navigation multiple indicator, observe that DISTANCE TO GO readout agrees (±002) with STAGE I DISTANCE TO GO readout on control indicator.

4. On control indicator, set stage selector switch to STAGE II ACTIVE. Then, observe that STAGE II DISTANCE TO GO readout is decreasing.

5. On air navigation multiple indicator, observe that DISTANCE TO GO readout is decreasing.

6. On air navigation multiple indicator, observe that DISTANCE TO GO readout agrees (±002) with STAGE II DISTANCE TO GO readout on control indicator.

7. On control indicator, set STAGE I and STAGE II DESIRED TRACK ANGLE readouts to 180.0. Then, observe that STAGE II DISTANCE TO GO readout is increasing.

8. On control indicator set stage selector switch to STAGE I ACTIVE. Then, observe that STAGE I DISTANCE TO GO readout is increasing.



**Figure 7. Example Page from LTTA Bench Checkout and Troubleshooting Procedures for Computer Set AN/ASN-35 (Section 3 of LTTA)**

Table 3-1. Computer Set AN/ASN-35 Troubleshooting Crossreference (Continued)

| STEP FAILED | INDICATION | PROCEDURE |
|---|---|---|
| 3-5/2 Cont'd | | If all ac voltages are present and vary, air navigation multiple indicator is faulty. Otherwise, control indicator is faulty. Perform control indicator bench checkout procedure. |
| 3-5/3 | On air navigation multiple indicator and control indicator, DISTANCE TO GO readouts do not agree. | Figure 3-3. |
| 3-5/4 | On control indicator, STAGE II DISTANCE TO GO readout not decreasing. | Control indicator faulty. Perform control indicator bench checkout procedure. |
| 3-5/5 | On air navigation multiple indicator, DISTANCE TO GO readout not decreasing. | Control indicator faulty. Perform control indicator bench checkout procedure. |
| 3-5/6 | On control indicator and air navigation multiple indicator, DISTANCE TO GO readouts do not agree. | Control indicator faulty. Perform control indicator bench checkout procedure. |
| 3-5/7 | On control indicator, STAGE II DISTANCE TO GO readout not increasing. | On test harness, check for a 15- to 35-V positive pulse, 35- to 85-ms duration occurring 9 to 11 times per minute at test points E12 (hot) and E5 (rtn). If pulse is present, control indicator is faulty. Otherwise, navigational computer track resolver drive 300 is faulty. Perform track resolver drive bench checkout procedure. |
| 3-5/8 | On control indicator, STAGE I DISTANCE TO GO readout not increasing. | Control indicator faulty. Perform control indicator bench checkout procedure. |



**Figure 8. Example Page from LTTA Bench Checkout and Troubleshooting Procedures for Computer Set AN/ASN-35 (Section 3 of LTTA)**

T.O. 5N1-3-8-2-TS-1

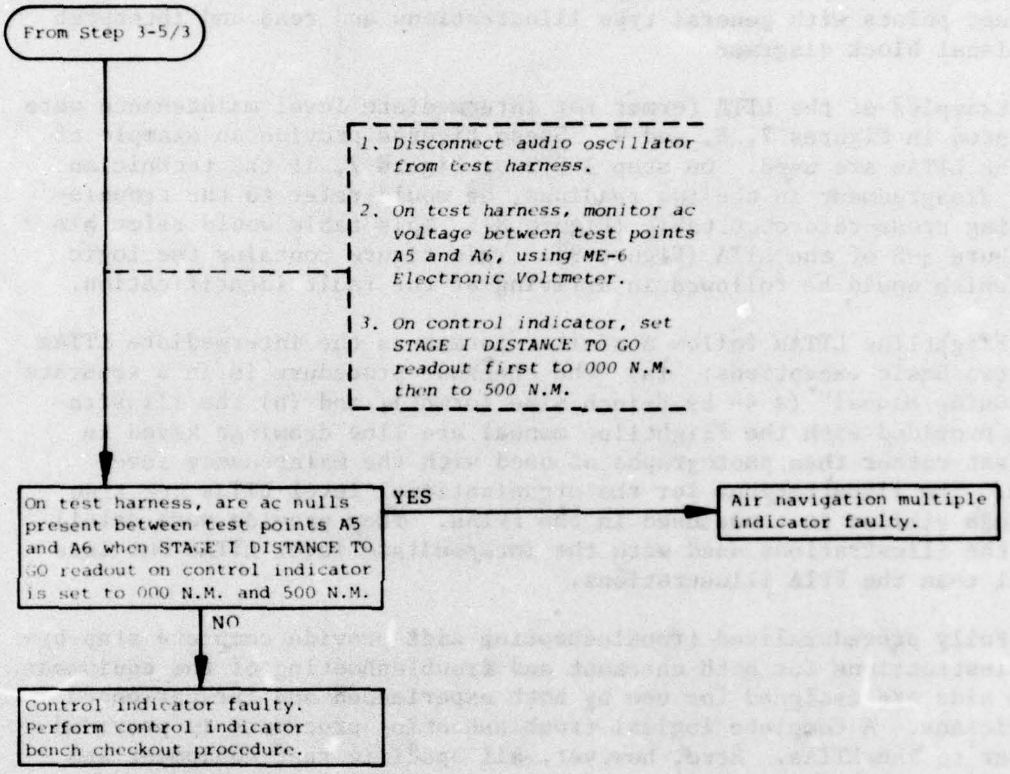



**Figure 3-3. Computer Set Troubleshooting for Failed Bench Checkout Procedure 3-5/3**

3-28

**Figure 9. Example Page from LTTA Bench Checkout and Troubleshooting Procedures for Computer Set AN/ASN-35 (Section 3 of LTTA)**

The LTTAs also contain functional block diagrams as additional aids to the technician although use of these diagrams is generally not required. LTTAs are similar to conventional manuals in that they are prepared for the more experienced technicians. Technicians are assumed to be able to properly choose and use test equipment, locate most parts and test points with general type illustrations and read and interpret functional block diagrams.

Examples of the LTTA format for intermediate level maintenance were presented in Figures 7, 8, and 9. These figures provide an example of how the LTTAs are used. On step 3-5.3 of Figure 7, if the technician found disagreement in the two readings, he would refer to the trouble-shooting cross-reference table (Figure 8). This table would refer him to Figure 3-3 of the LTTA (Figure 9). This figure contains the logic tree which would be followed in arriving at the fault identification.

Flightline LTTAs follow a similar format as the intermediate LTTAs with two basic exceptions: (a) the checkout procedure is in a separate "Job Guide Manual" (a 4- by 8-inch size format), and (b) the illustrations provided with the flightline manual are line drawings keyed to the text rather than photographs as used with the maintenance level LTTAs. The illustrations for the organizational level LTTAs are line drawings similar to those used in the FPTAs. They provide more detail than the illustrations used with the intermediate level LTTAs but less detail than the FPTA illustrations.

Fully proceduralized troubleshooting aids provide complete step-by-step instructions for both checkout and troubleshooting of the equipment. These aids are designed for use by both experienced and inexperienced technicians. A complete logical troubleshooting procedure is provided similar to the LTTAs. Here, however, all specific test equipment and tools are called out in each section as they are required. Each prime hardware item and the more complex test equipments and tools mentioned in the body of the text are accompanied by a callout number, in parentheses, keyed to an illustration of the items appearing on that same page or a facing page. For test equipment the illustrations appear in a fold-out page at the back of each section (Figure 15). As soon as the technician becomes familiar with the test equipment he need no longer refer to the fold-outs. The FPTAs are complemented by maintenance support information manuals. These manuals contain instructions on test equipment operation, special testing procedure and wiring diagrams. They are not required for use with the FPTAs but are available to the technician if desired. To facilitate use of the aids by personnel with experience on the equipment, the basic checks, expected readings, and tolerances are underlined. Underlined information permits the experienced technician to rapidly scan the text and thus focus his attention on pertinent information only.

Examples of the FPTA format covering the same malfunction dealt with in the LTTA example (non-agreement of DISTANCE-MILES and STAGE I

DISTANCE TO GO counters) appear in Figures 10 through 15. The beginning of the checkout procedure is presented in Figure 10. The FPTA page (where the malfunction is encountered) is shown as Figure 11. The proceduralized troubleshooting procedure to be followed begins on the page shown in Figure 12. (Troubleshoot malfunction No. 37 continues on the pages shown in Figures 13 and 14.) The fold-out referred to in Step 1 (Figure 10) appears at the end of the checkout procedure and is depicted in Figure 15.

## DEVELOPMENT OF FPTA AND LTTA DOCUMENTATION

The FPTAs for both organizational and intermediate level maintenance were developed under contract with Kentron Hawaii, Ltd. The FPTAs were developed in accordance with the requirements of the draft specification contained in AFHRL-TR-73-43(I). This specification provides detailed requirements for the content and format of the data. In addition, it requires that a thorough task identification and analysis be performed and that specific "subproducts" be generated during the task analysis and data development. The subproducts are required to ensure that the contractor follows development procedures which will provide high quality data, i.e., data that are complete and provide the technician with all the information he needs. The procedures also ensure that the data are written at a level of detail suitable for the intended user.

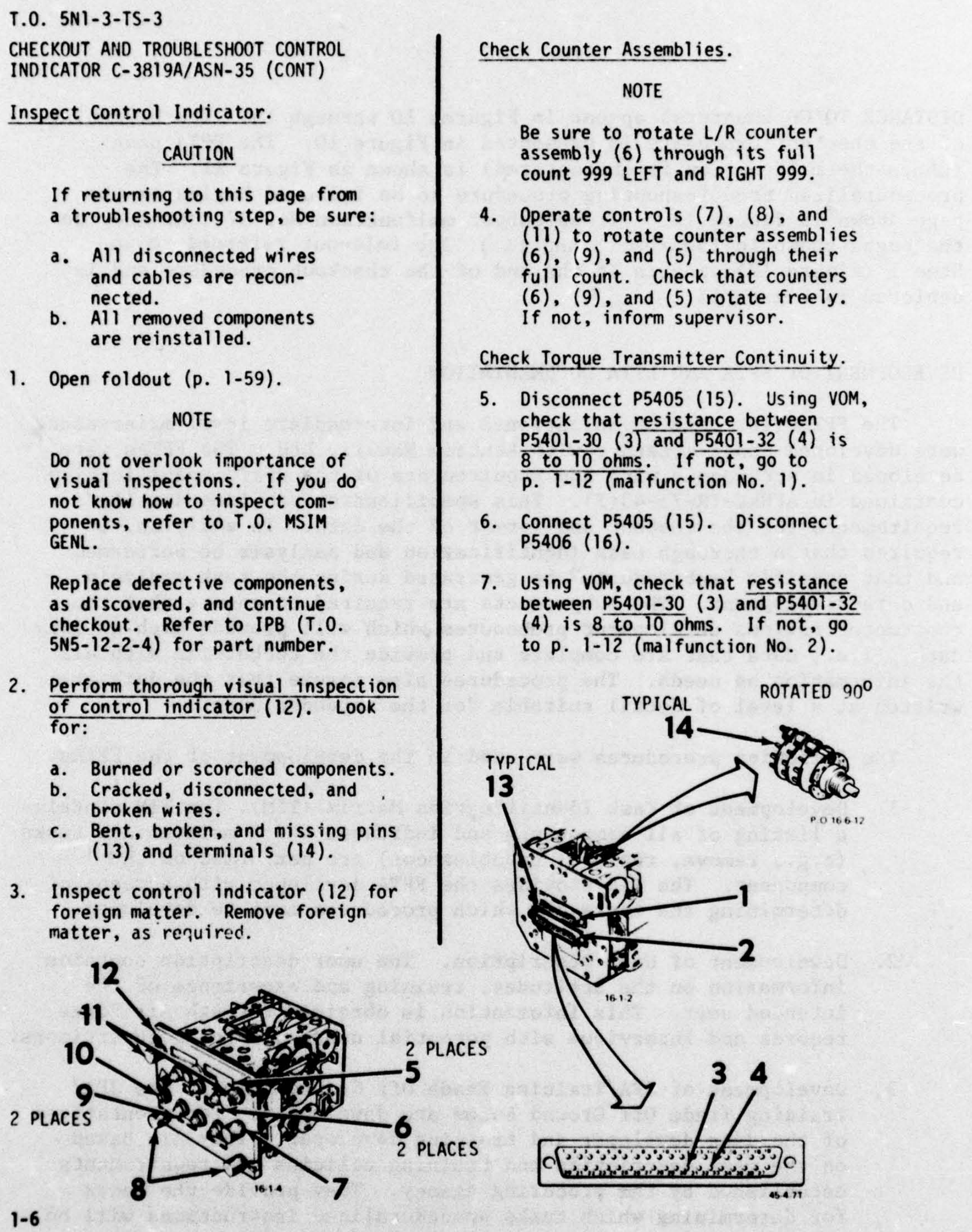
The following procedures were used in the development of the FPTAs:

1. Development of Task Identification Matrix (TIM). The TIM contains a listing of all components and indicates which maintenance tasks (e.g., remove, replace, troubleshoot) are performed on the component. The TIM provides the FPTA developer with a means of determining the tasks for which procedures must be developed.

2. Development of User Description. The user description contains information on the aptitudes, training and experience of the intended user. This information is obtained through Air Force records and interviews with potential users and their supervisors.

3. Development of JPA/Training Trade Off Ground Rules. The JPA/ Training Trade Off Ground Rules are developed by representatives of the data developer and training developer. They are based on the user description and training policies and requirements established by the procuring agency. They provide the basis for determining which tasks proceduralized instructions will be developed for and the level of detail to be used.

4. Development of the Level-of-Detail Guide. The Level-of-Detail Guide provides the individual writing the procedure with guidelines for determining the level of detail to be provided


T.O. 5N1-3-TS-3

CHECKOUT AND TROUBLESHOOT CONTROL INDICATOR C-3819A/ASN-35 (CONT)

Inspect Control Indicator.

CAUTION

If returning to this page from a troubleshooting step, be sure:

a. All disconnected wires and cables are reconnected.
b. All removed components are reinstalled.

1. Open foldout (p. 1-59).

NOTE

Do not overlook importance of visual inspections. If you do not know how to inspect components, refer to T.O. MSIM GENL.

Replace defective components, as discovered, and continue checkout. Refer to IPB (T.O. 5N5-12-2-4) for part number.

2. Perform thorough visual inspection of control indicator (12). Look for:

a. Burned or scorched components.
b. Cracked, disconnected, and broken wires.
c. Bent, broken, and missing pins (13) and terminals (14).

3. Inspect control indicator (12) for foreign matter. Remove foreign matter, as required.

Check Counter Assemblies.

NOTE

Be sure to rotate L/R counter assembly (6) through its full count 999 LEFT and RIGHT 999.

4. Operate controls (7), (8), and (11) to rotate counter assemblies (6), (9), and (5) through their full count. Check that counters (6), (9), and (5) rotate freely. If not, inform supervisor.

Check Torque Transmitter Continuity.

5. Disconnect P5405 (15). Using VOM, check that resistance between P5401-30 (3) and P5401-32 (4) is 8 to 10 ohms. If not, go to p. 1-12 (malfunction No. 1).

6. Connect P5405 (15). Disconnect P5406 (16).

7. Using VOM, check that resistance between P5401-30 (3) and P5401-32 (4) is 8 to 10 ohms. If not, go to p. 1-12 (malfunction No. 2).



1-6

**Figure 10. Example Page from FPTA Checkout and Troubleshoot Procedures for Navigational Computer AN/ASN-35**

CHECKOUT AND TROUBLESHOOT CONTROL INDICATOR C-3819A/ASN-35 (CONT)

Check Zero Switches SW5403, SW5404.

52. Set FUNCTION switch (65) to STAGE RECYCLING. Rotate ACTIVE/OFF switch (36) to STAGE I ACTIVE/STAGE II OFF.

53. Set AUTO-MAN-OFF switch (40) to AUTO. ACTIVE/OFF switch (36) should remain STAGE I ACTIVE/STAGE II OFF. If not, go to p. 1-35.

54. Rotate ACTIVE/OFF switch (36) to STAGE I OFF/STAGE II ACTIVE. ACTIVE/OFF switch (36) should remain STAGE I OFF/STAGE II ACTIVE. If not, go to p. 1-36.

Check DISTANCE TO GO Counter Operation.

55. Set FUNCTION switch (65) to ALONG TRACK. Set DISTANCE-MILES counter (66) to 000.

56. Set DISTANCE TO GO counters (38) and (39) to 000 000. Rotate ACTIVE/OFF switch (36) to STAGE I ACTIVE/STAGE II OFF.

57. Set COUNTER SETTING switch (63) to FAST INCR. Return switch (63) to 0, as required, to stop DISTANCE-MILES counter (66) at 750. Check that:

    a. STAGE I DISTANCE TO GO counter (39) indicates 750. If not, go to p. 1-37.
    b. ALONG TRACK-MILES counter (31) indicates 750 ±001. If not, go to p. 1-39.

58. Return DISTANCE-MILES counter (66) to 000. Return STAGE I DISTANCE TO GO counter (39) to 000.

59. Set COUNTER SETTING switch (63) to FAST DECR. Return switch (63) to 0, as required, to stop DISTANCE-MILES counter (66) at 250. Check that:

    a. STAGE I DISTANCE TO GO counter (39) indicates 250. If not, go to p. 1-41.
    b. ALONG TRACK-MILES counter (31) indicates 250 ±001. If not, go to p. 1-39.

60. Rotate ACTIVE/OFF switch (36) to STAGE I OFF/STAGE II ACTIVE. Return DISTANCE-MILES counter (66) to 000.

61. Set COUNTER SETTING switch (63) to FAST INCR. Return switch (63) to 0, as required, to stop DISTANCE-MILES counter (66) at 750. Check that:

    a. STAGE II DISTANCE TO GO counter (38) indicates 750. If not, go to p. 1-43.
    b. ALONG TRACK-MILES counter (31) indicates 750 ±001. If not, go to p. 1-45.

62. Return DISTANCE-MILES counter (66) to 000. Return STAGE II DISTANCE TO GO counter (38) to 000.

63. Set counter setting switch (63) to FAST DECR. Return switch (63) to 0, as required, to stop DISTANCE-MILES counter (66) at 250. Check that:

    a. STAGE II DISTANCE TO GO counter (38) indicates 250. If not, go to p. 1-47.
    b. ALONG TRACK-MILES counter (31) indicates 250 ±001. If not, go to p. 1-45.

Check Stage Switching.

64. Set FUNCTION switch (65) to STAGE RECYCLING.

65. Set DISTANCE TO GO counters (38) and (39) to 002 002. Rotate ACTIVE/OFF switch (36) to STAGE I ACTIVE/STAGE II OFF. Set AUTO-MAN-OFF switch (40) to AUTO.

66. Decrease STAGE I DISTANCE TO GO counter (39) to 000. Check that ACTIVE/OFF switch (36) changes to STAGE I OFF/STAGE II ACTIVE. If not, go to p. 1-48.

67. Depress and hold PRESS TO TEST switch (44). Using RMS voltmeter,



Figure 11. Example Page from FPTA Checkout and Troubleshoot Procedures for Navigational Computer AN/ASN-35

17. Using VOM, check that resistance between SW5402-C7 (3) and SW5402-C8 (2) is 1 ohm or less. If not, go to step 20. If VOM indicates 1 ohm or less, go to next step.

18. Using VOM, check that C5411 (1) is good. If not, go to step 21. If C5411 (1) is good, go to step 24.

19. Replace TX5401, transmitter, torque (17) (vol. 6, p. 3-1) and go to p. 1-1.

20. Replace SW5402, switch (7) (Vol. 6, p. 3-1) and go to p. 1-1.

21. Replace C5411, capacitor, 0.02 uF (1) and go to p. 1-1.

22. Replace C5404, capacitor, 0.05 uF (8) and go to p. 1-1.

23. Replace C5412, capacitor, 0.02 uF (6) and go to p. 1-1.

24. Using control indicator wiring diagram (vol. 6) check wiring. Repair or replace defective wires and go to p. 1-1.

TROUBLESHOOT MALFUNCTION NO. 36
ENDS HERE

Troubleshoot Malfunction No. 37.

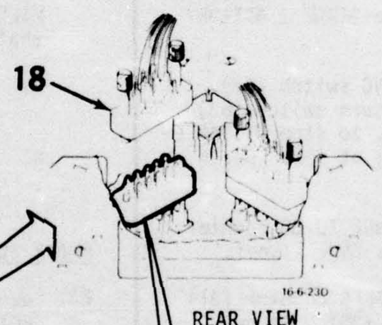
SUMMARY NOTE

When DISTANCE-MILES counter indicates 250, STAGE I DISTANCE TO GO counter does not indicate 250.

1. Set ON/OFF switch (54) to OFF and unplug P5402 (11). Using VOM, check that 115V-1/2A SLO-BLO fuse (53) is good. Replace fuse (53), as required, and go to step 2.

2. Using VOM, check that resistance between P5402-2 (10) and P5402-3 (9) is 60 to 80 ohms. If not, go to step 7. If VOM indicates 60 to 80 ohms, go to next step.

3. Remove L/H and R/H along track counter assemblies (16) and (15) (vol. 6, p. 3-1) and go to next step.



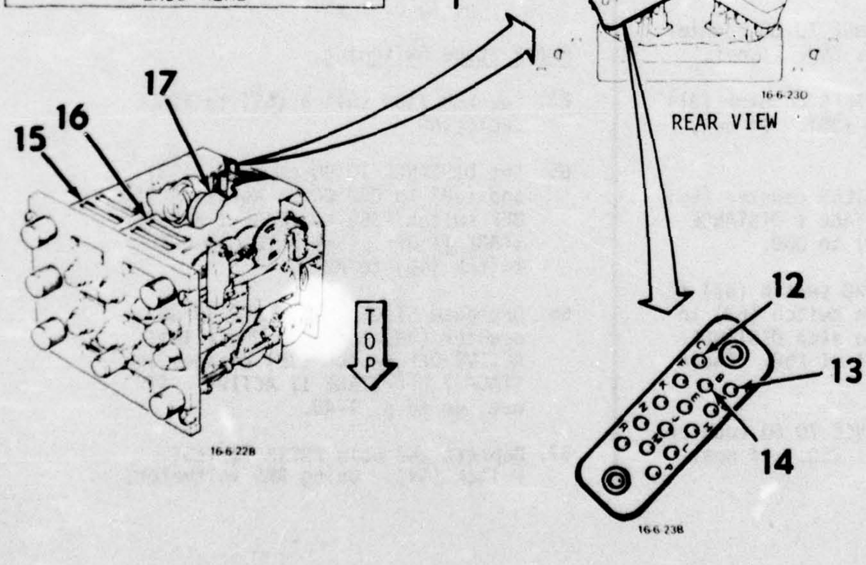






**Figure 12. Example Page from FPTA Checkout and Troubleshoot Procedures for Navigational Computer AN/ASN-35**

CHECKOUT AND TROUBLESHOOT CONTROL INDICATOR C-3819A/ASN-35 (CONT)

Troubleshoot Malfunction No. 37 (Cont).

4. Check that right counter magnet assembly K5405 (4) adjustment is good. If not, go to step 11. If adjustment is good, go to next step.

5. Check that right counter magnet core K5405 (3) adjustment is good. If not, go to step 12. If adjustment is good, go to next step.

6. Inform supervisor malfunction is mechanical and located in L/H along track counter assembly (2).

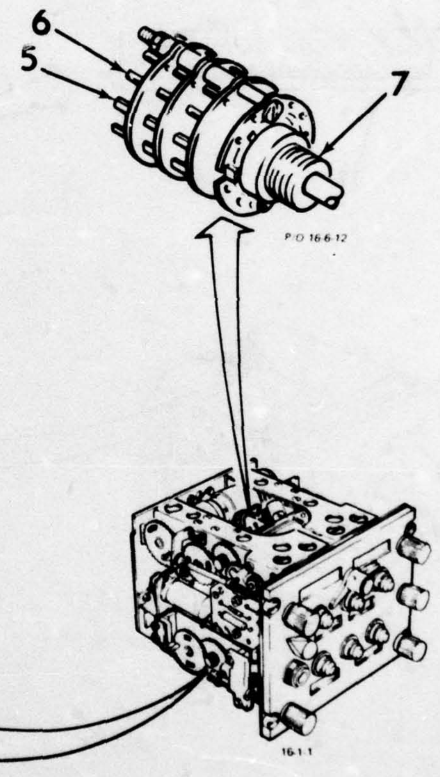
7. Using VOM, check that resistance between SW5402-C10 (5) and SW5402-C11 (6) is 1 ohm or less. If not, go to step 13. If VOM indicates 1 ohm or less, go to next step.

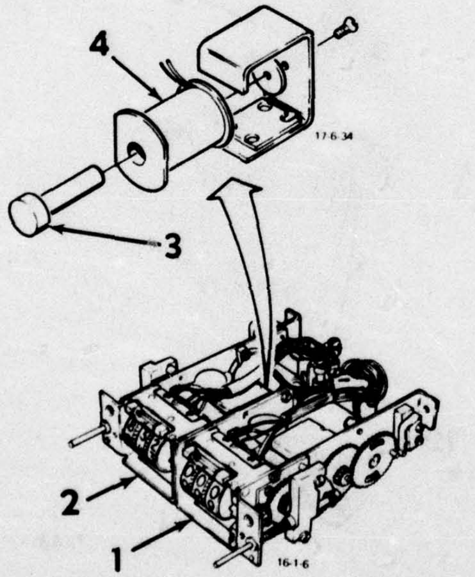
8. Disconnect P5406 (8) and go to next step.

9. Using VOM, check that resistance between J5406-J (10) and J5406-F (9) is 60 to 80 ohms. If not, go to step 14. If VOM indicates 60 to 80 ohms, go to next step.

10. Using control indicator wiring diagram (vol. 6) check wiring. Repair or replace defective wires and go to p. 1-1.

11. Adjust right counter magnet assembly K5405 (4) (vol. 6, p. 5-1) and go to step 15.




1-42

Figure 13. Example Page from FPTA Checkout and Troubleshoot Procedures for Navigational Computer AN/ASN-35

T.O. 5N1-3-TS-3

12. Adjust right counter magnet core K5405 (3) (vol. 6, p. 5-1) and go to step 15.

13. Replace SW5402, switch (7) (vol. 6, p. 3-1) and go to p. 1-1.

14. Replace K5405, magnet counter assembly (4) (vol. 5, p. 3-1) and go to step 15.

15. Instal L/H and R/H along track counter assemblies (2) and (1) (vol. 6, p. 3-1). Plug in P5402 (11). Set ON/OFF switch (54) to ON and go to p. 1-1.

| TROUBLESHOOT MALFUNCTION NO. 37 ENDS HERE |
|---|

Troubleshoot Malfunction No. 38.

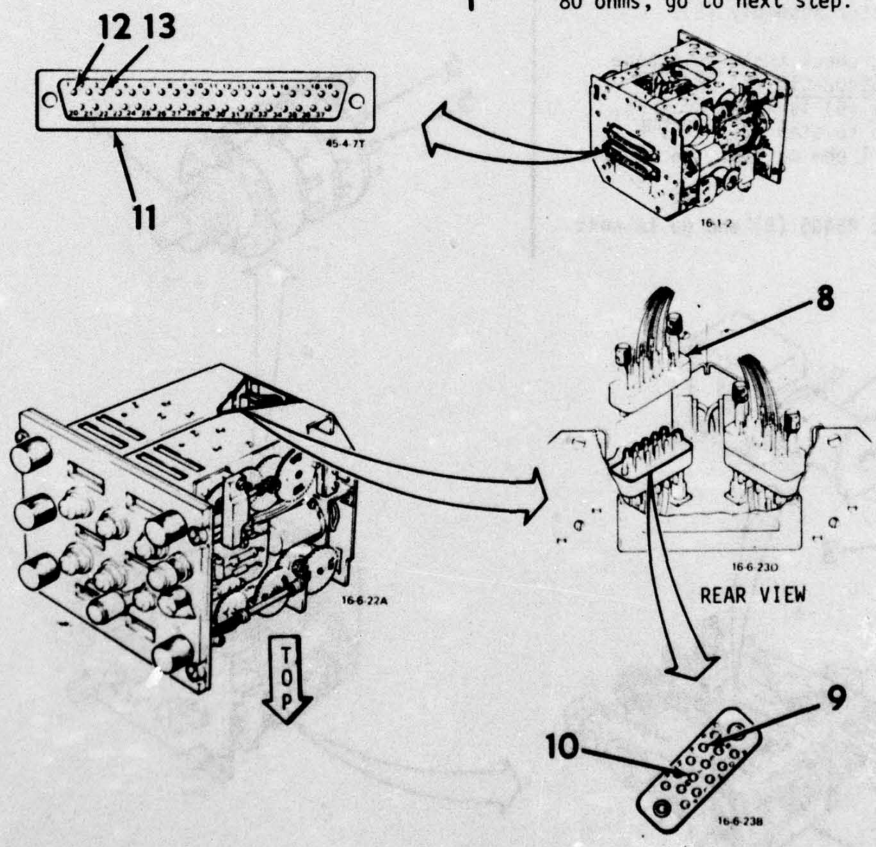
SUMMARY NOTE

When DISTANCE-MILES counter indicates 750, STAGE II DISTANCE TO GO counter does not indicate 750.

1. Set ON/OFF switch (54) to OFF. Using VOM, check that 115V-1/2A SLO-BLO fuse (53) is good. Replace fuse (53), as required, and go to next step.

2. Unplug P5402 (11) and go to next step.

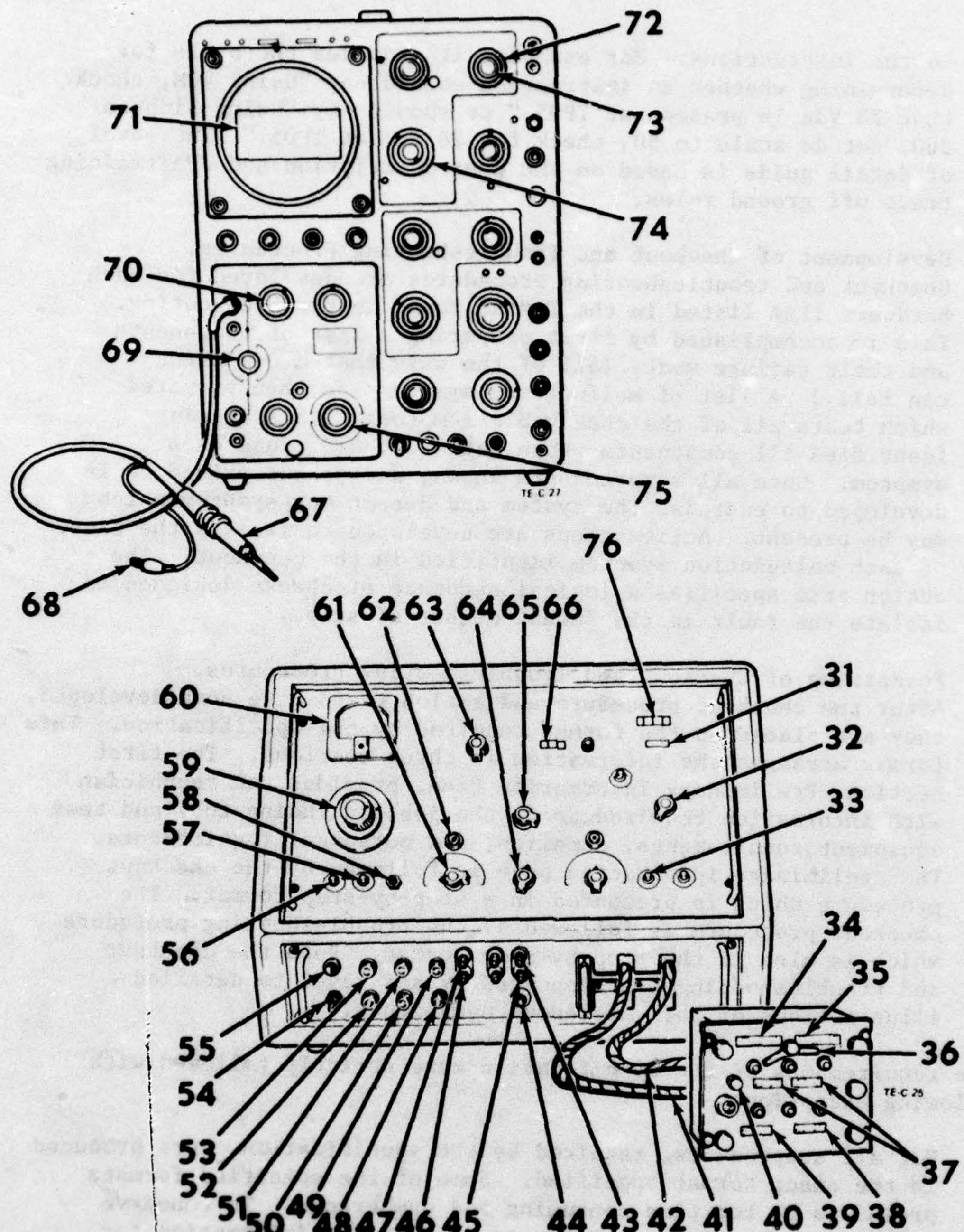
3. Using VOM, check that resistance between P5402-1 (12) and P5402-3 (13) is 60 to 80 ohms. If not, go to step 8. If VOM indicates 60 to 80 ohms, go to next step.




1-43

Figure 14. Example Page from FPTA Checkout and Troubleshoot Procedures for Navigational Computer AN/ASN-35

T. O. 5N1-3-TS-3




1-59/(1-60 BLANK)

Figure 15. Example Page from FPTA Checkout and Troubleshoot Procedures for Navigational Computer AN/ASN-35

in the instructions. For example, it provides the basis for determining whether an instruction should say "Using VOM, check that 28 Vdc is present at TP05," or should say "Using Simpson 260, set dc scale to 50, check for 28 Vdc at TP05." The level of detail guide is based on the user description and JPA/training trade off ground rules.

5. Development of Checkout and Troubleshooting Procedures. Checkout and troubleshooting procedures are developed for each hardware item listed in the TIM as found in troubleshooting. This is accomplished by first preparing a list of components and their failure modes (all of the ways that a component can fail.) A list of malfunction symptoms is then prepared which tests all of the observable symptoms. This listing identifies all components whose failure could cause each symptom. Once all symptoms are known, a checkout procedure is developed to exercise the system and detect any symptom which may be present. Action trees are developed to isolate the cause of each malfunction symptom identified in the checkout. The action tree specifies a logical sequence of checks designed to isolate the fault in the fewest number of steps.

6. Formatting of Checkout and Troubleshooting Procedures. After the checkout procedure and action trees have been developed, they are placed in the format required by the specification. This format arranges the information in three sections. The first section, Preliminary Information Page, provides the technician with information required to do the job, including tool and test equipment requirements, supplies, and personnel requirements. The preliminary information page is followed by the checkout procedure which is presented in a step-by-step format. The checkout procedure is followed by the troubleshooting procedure which is also in the step-by-step format. Both the checkout and troubleshooting are supported by and keyed to detailed illustrations of the referenced components.

The requirements of the specification were strictly followed with the following exceptions:

1. Not all subproducts, required by the specification, were produced in the exact format specified. Some of the specified formats proved to be too time consuming and cumbersome. To conserve resources, the contractor was to provide the information for in-process reviews in altered formats. Although the formats were altered, the analysis procedures used to develop the information were not altered.

2. The specification requires that all illustrations be placed on the facing or same page as the procedure referencing the illustration. It was realized early in the development process

that this requirement would result in an excessive number of pages. It was observed that many of the illustrations of test equipment would be repeated from page to page without change. Therefore, to reduce page requirements and unnecessary repetition, the contractor was permitted to use fold-out pages to present these illustrations. Use of the fold-outs reduced the total number of pages by approximately 50 percent.

In-process reviews were held throughout the development process at points specified in the specification. A strong emphasis was placed on these reviews to ensure high quality data.

The contractor was required to accomplish a 100 percent validation of all procedures. Dedicated equipment was provided to the contractor at his plant for this purpose.

The LTTAs for organizational level maintenance were developed by Westinghouse Corporation. The LTTAs were developed as part of the Air Force technical order improvement program. Under this program Job Guide Manuals and LTTAs were developed for organization level equipment maintenance of the C-141. These aids are presently in operational use. The LTTAs were developed according to MIL-M-38800A as modified by a requirement for a complete fault analysis. Specific developmental procedures or techniques are not prescribed by this specification, but are left to the discretion of the contractor. Thus, emphasis is placed by the procuring agency on the product rather than on both the process and product which is the case in the development of FPTAs. Dedicated aircraft were available for hands-on analysis and tryout of the checkout and troubleshooting procedures.

The intermediate level LTTAs were developed specifically for this project by Lockheed Electronics Company under contract with AFHRL. The aids were developed according to MIL-M-38800A as modified by a requirement for a task analysis. As with the organizational level LTTAs, specific developmental procedures were not specified or required. The contractor was given freedom to use his own procedures. Complete AN/APN-147 and AN/ASN-35 systems were provided to the contractor at his plant for use in the task analysis and validation of procedures. A 100 percent validation of all checkout procedures and selected troubleshooting trees was required.

In-process reviews were held periodically at the contractor's facility to ensure the accuracy and adequacy of the data. The reviews were held at approximately the same intervals as in-process reviews for the FPTA development. Approximately the same level of effort was expended by the procuring agency in supervising the development of FPTAs and LTTAs.

## Section III

## ACCURACY ANALYSIS

One of the goals of the project was to evaluate the relative accuracy of FPTAs and LTTAs and their adequacy for isolating equipment faults. This was accomplished for two purposes:

1. To provide data relative to the question of whether the stringent FPTA development procedures produce more accurate data.

2. To provide a pool of potential problems for use in the evaluation. This pool provided a list of problems for which it was known that FPTAs, LTTAs, and TOs provide adequate procedures and information for isolating the faults. The job performance tests were built to measure troubleshooting performance on 15 problems from this list.

### SELECTION OF PROBLEMS

The equipment problems against which the documentation types were evaluated were selected after an intensive review of worldwide Air Force maintenance actions on the AN/APN-147 and AN/ASN-35 systems for calendar year 1974. The data contained in these reports were summarized to provide identification of maintenance areas which appeared to be logical and representative candidates for development of troubleshooting test problems. In an attempt to provide field verification of the correctness of the data summarizations, the results were discussed in detail with maintenance personnel at Charleston AFB, South Carolina. (This base was not included in the field evaluation effort). As a result of the Charleston AFB interviews, detailed information, not available from the AFLC reports, was obtained on the specific parts or components which were contributing most to the maintenance problems of the AN/APN-147 and the AN/ASN-35. This information was considered in selection of the specific trouble-shooting test problems. A total of 30 malfunctions were identified (15 AN/APN-147 and 15 AN/ASN-35). Each of the malfunctions selected was located on an applicable system schematic to verify that the problems selected were satisfactorily distributed throughout the system.

### METHOD OF CHECKING FOR ACCURACY

Each of the candidate problems was inserted in working equipment to determine the operational symptoms associated with the failed equipment part or component. Once this action had resulted in identification of the known effects of the fault, a systematic evaluation of the accuracy of the technical documentation types in supporting the isolation of the faults was undertaken. This was undertaken using

each type of data to isolate the fault. Records were maintained on the errors found in the data and whether the troubleshooting procedure led to isolation of the problem. This approach made use of the same (primary and test) equipment and aids as used in the field evaluation portion of the experiment.

It was necessary to use substitutes for some problems to assure compatibility with the degree of simulation fidelity employed in the Air Force simulations of a C-141A cockpit and intermediate (shop) level maintenance benches. As an example, the technical documentation guiding isolation of certain of the faults originally selected directed the troubleshooter to the Horizontal Situation Indicator (HSI). The HSI was represented by a nonfunctioning simulation of the Air Force trailer and thus the particular fault could not be resolved by the technical documentation/equipment simulation combination. In an instance such as this, a new candidate fault was selected and the ability of the types of technical documentation to find it was verified. Any editorial or content problems with the candidate types of technical documentation discovered as a result of following this process were reported to the Air Force technical monitor for correction. Examples of some of the specific problems encountered with each of the data types are specified in the following sections.

## FINDINGS

The results of the accuracy analysis are presented in the following sections.

### FPTAs

A number of typographical and technical errors were found in the FPTAs. These may be classified into four categories.

1. Inadequate illustration. In some cases the illustrations were unclear or the call-out arrows were not properly placed to clearly identify the referenced component.

2. Incorrect steps or values. In some instances the technician is directed to go to an incorrect step. In other instances incorrect tolerances and meter readings are given. A sufficient number of such errors were encountered to indicate a need for increased quality control in these areas.

3. Inadequate tolerances. In some instances specific values are specified for some readings or checks. This does not allow sufficient tolerances for variations between individual systems. This rigidity can lead to good components being incorrectly

identified as bad. For example, steps 5 and 6 on page 1 - 4 of T.O.5N1-3-TS-1 specifies that the "distance to go" indicator must count down to "000" in 10 minutes. Individual differences in equipment result in this countdown seldom occurring at exactly 10 minutes. A tolerance of 9.5 to 10.5 minutes would have alleviated this problem.

4. Clerical errors. Clerical errors were found to a degree throughout the FPTAs. Errors of this type can be relatively minor or can cause the procedure to be completely ineffective. Increased quality control in this area is needed.

LTTAs

The errors found in the LTTAs were similar in nature to those found in the FPTAs.

1. Incorrect tolerances. In some instances referenced values for readings gave no permissible tolerances, causing technicians to incorrectly classify components as being faulty.

2. Unclear intent. It was unclear to the technicians that a detailed check procedure followed the minimum checkout of equipment. Instances of unclear designation of specific switches or counters were found. A further instance of unclear intent was found where technicians were given multiple symptoms. These were not adequately identified to permit cross-reference with the symptoms contained in T.O.141A-2-8J6-2 (Checkout). Finally, word descriptions of the same symptom appearing at different places in the LTTA were inconsistent, again leading to confusion in intent.

3. Clerical errors. Clerical errors were found to a degree throughout the LTTA. The errors can have impacts ranging from negligible to completely disruptive on success with the procedure. Increased quality control is needed.

Figure 16 contains a summarization of the documentation problems by number and nature found for each of the 15 troubleshooting problems used in the experimental evaluation portion of this study.

In perusing Figure 16, the reader is cautioned against assigning an equal severity to each indicated problem. In such a comparison, FPTAs would have been credited with 29 problems and LTTAs with only 14. The conclusion might be erroneously made that LTTAs were twice as problem-free as were FPTAs. FPTAs are written to a much greater level of detail than are LTTAs and the problems noted were frequently of a more minor nature than those with LTTAs. Each document type had problems and these problems had varied levels of severity. The number

| Troubleshooting Problem Number | Document Type | Number of Problems with Document | Nature of Problem |
|---|---|---|---|
| 1 | FPTA<br>LTTA | 2<br>1 | Incorrect instruction (2)<br>Switch identification (1) |
| 2 | FPTA | 3 | Misleading instruction (2)<br>No tolerance for reading (1) |
| | LTTA | 4 | Incorrect reference (1)<br>No tolerance for reading (1)<br>Unclear procedure (1)<br>Unclear meaning (1) |
| 3 | FPTA | 2 | Incorrect reference (1)<br>Unclear reference (1) |
| | LTTA | 2 | Switch identification (1)<br>Unclear wording (1) |
| 4 | FPTA | 3 | Misleading instruction (2)<br>No tolerance for reading (1) |
| | LTTA | 0 | |
| 5 | FPTA | 2 | Insufficient tolerances (1)<br>Incorrect identification (1) |
| | LTTA | 5 | Insufficient tolerances (1)<br>Unclear procedure (4) |
| 6 | FPTA | 1 | Inaccurate reference (1) |
| | LTTA | 1 | Incorrect reference (1) |
| 7 | FPTA | 2 | Switch identification (2) |
| | LTTA | 0 | |
| 8 | FPTA | 0 | |
| | LTTA | 0 | |
| 9 | FPTA | 3 | Insufficient tolerances (1)<br>Incorrect instruction (1)<br>Incomplete instruction (1) |
| | LTTA | 0 | |

**Figure 16. Summarization of Problems Encountered with FPTA and LTTA Documentation for Troubleshooting Problems Used in Study**

| Troubleshooting Problem Number | Document Type | Number of Problems with Document | Nature of Problem |
|---|---|---|---|
| 10 | FPTA | 3 | Incorrect instruction (3) |
| | LTTA | 0 | |
| 11 | FPTA | 1 | Incorrect reference (1) |
| | LTTA | 2 | Unclear instructions (2) |
| 12 | FPTA | 6 | Insufficient tolerances (4)<br>Unclear instruction (2) |
| | LTTA | 0 | |
| 13 | FPTA | 0 | |
| | LTTA | 0 | |
| 14 | FPTA | 0 | |
| | LTTA | 0 | |
| 15 | FPTA | 1 | Unclear instruction (1) |
| | LTTA | 1 | Unclear procedure (1) |

**Figure 16. Summarization of Problems Encountered with FPTA and LTTA Documentation for Troubleshooting Problems Used in Study (Concluded)**

of errors found is not greater than would normally be expected in any TO. All errors found can be corrected relatively easily. If sufficient funds had been available for a more complete verification, it is likely that most of the errors would have been detected and corrected. In all instances, however, it was concluded that these problems were soluble.

Problems from the original list of 30 candidate faults which were not selected for inclusion were excluded for a variety of reasons. The major reasons for rejection were equipment centered (required equipment not included in the mockup or equipment that was not available). Four of the 15 nonselected problems were rejected on the basis of inaccuracies or other problems with the FPTA or LTTA.

In these four instances, results were as follows:

For two problems the LTTA permitted the location of the fault, but the FPTA directed the technician along troubleshooting paths which resulted in identification of a good part as being bad. In the remaining two instances neither the FPTA nor LTTA detected the existence of the fault, (i.e., the checkout procedure led to the conclusion that the system was operating satisfactorily).

## Section IV

## COST COMPARISON

A major consideration in determining if either FPTAs or LTTAs should be adopted for use with existing and future Air Force systems concerns their cost. More specifically, how much more would have to be invested to provide either FPTAs or LTTAs as an adjunct to existing TOs or as a complete replacement.

Although it was a project goal to provide complete answers to these questions, the task proved to be more difficult than anticipated. First of all, this study was concerned only with technical data for troubleshooting. It was impossible to equate FPTAs and LTTAs with the conventional TOs because of differences in content, differences in data base development, and time of development. First, troubleshooting data in the TO was mixed with other types of data throughout the manual (it was for this reason, among others, that the more compact FPTAs and LTTAs were developed). Secondly, the existing TO did serve as a partial data base for the FPTA and LTTA. A true comparison would be possible only if all three types of data were developed independently on a new system. Finally, the TO was developed a number of years ago when labor rates, and dollar costs, were different. The TO had also been updated and modified a number of times since initial development. For these reasons subsequent analyses were restricted to a comparison of FPTAs and LTTAs only. The results are reported below along with some general comments on additional considerations to be made in comparing technical data systems.

### COMPARISON OF FPTA AND LTTA COSTS

Since the FPTAs and LTTAs cover the same tasks and were developed from the same data base, a direct comparison of costs is possible. The costs are presented in Table 1. They are presented in terms of cost per page unit and total cost. A page unit is defined as the area contained in a standard 8 1/2- by 11-inch page. The LTTAs for organizational level maintenance are printed in the 4- by 8-inch format. The number of pages has been converted to page units to permit a meaningful comparison.

As may be seen from Table 1, a total of 880 page units were required to present the FPTAs and 623 page units were required to present the LTTAs. The largest number of page units are required for the intermediate level aids. A total of 809 page units were required for the FPTAs while only 545 page units were required for the LTTAs. Thus, 264 or 48 percent more pages werc required to present the FPTA at the intermediate level. Examination of the data suggests that the additional pages are required

primarily as a result of the extensive use of illustrations in the FPTA. The more detailed instructions in the FPTA also contribute to the requirement for more pages.

TABLE 1. COMPARISON OF COSTS EXPERIENCED FOR THE DEVELOPMENT OF FPTAs AND LTTAs FOR THE AN/APN-147 AND AN/ASN-35

| Technical Data Format | Cost Per Page Unit | Number of Page Units | Total Cost |
|---|---|---|---|
| FPTA | | | |
| Organizational | 203.56 | 71 | 14,451 |
| Intermediate | 203.56 | 809 | 164,680 |
| | | 880 | 179,131 |
| LTTA | | | |
| Organizational | 97.34 | 78 | 7,593 |
| Intermediate | 203.80 | 545 | 111,076 |
| | | 623 | 118,669 |

At the organizational level, the order of magnitude is reversed with slightly more page units required for the LTTA than for the FPTA. Seventy-eight pages were required for the LTTA and 71 pages were required for the FPTA. It would be expected that the FPTA would require more page units. Examination of the data reveals the reason for more pages being required for the LTTA. The reason is that the LTTAs for the organizational level contain schematics. The FPTAs do not have schematics (schematics for use with the FPTA are included with the job guide manuals discussed in a later section). When the LTTA schematics are excluded from the page count, it is observed that 59 page units are required to present the LTTAs. Thus, the FPTA requires 12 more page units to present the troubleshooting procedures.

From Table 1 it may also be seen that the cost per page unit was $203.56 for FPTAs, $97.34 for organizational level LTTAs and $203.80.

for intermediate level LTTAs[2]. The total cost for FPTAs was $179,131. The total cost for LTTAs was $118,669. Thus, the FPTAs cost significantly more (53%) than the LTTAs. There are two basic factors which contribute to higher cost for FPTAs. They are higher developmental costs and higher production costs. The higher developmental costs result from the more thorough and more rigidly specified task analysis required for the development of the FPTA. The FPTA task analysis requires some procedures (such as analysis of the capabilities of the user and development of the training/JPA trade off ground rules) that are not required in the LTTA task analysis. In addition, the FPTA task analysis requires that specific "subproducts" (such as the test equipment and tool use form) be developed and delivered in a specified format.

The second factor which contributes to the higher cost of FPTAs is higher production costs. The higher production costs result primarily from the larger number of pages required for the FPTA. As indicated above, the larger number of pages is due primarily to the extensive use of illustrations (at least one-third of each page is used for illustrations). Thus, considering the cost to develop the illustrations and the cost of producing the additional pages, the use of illustrations account for a significant portion of the higher cost of FPTAs.

## ADDITIONAL COST CONSIDERATIONS

The above discussion relates to the cost of data for troubleshooting only. Neither FPTAs nor LTTAs provide a complete system of technical data for maintaining the system. The TO, on the other hand, provides a complete system of technical data for maintaining all aspects of the system. (This difference in coverage is another reason that it was not considered appropriate to directly compare TO costs with FPTA and LTTA costs.)

A complete system of technical data based on the FPTA approach would require two additional types of data. Documentation presenting

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[2] In comparing the costs for developing FPTAs and LTTAs, two factors must be considered. The LTTAs for organizational level were developed under a large contract to prepare LTTAs and JGMs for the entire C-141 aircraft. Thus, overhead costs, etc., are spread out over a larger cost base. Secondly, the FPTAs and LTTAs were developed by contractors in different areas of the country where labor rates differ significantly. The FPTAs were developed by Kentron Hawaii, Ltd., in Dallas, Texas, a relatively low labor cost area. The intermediate level LTTAs were developed by Lockheed Electronics Company in Plainfield, New Jersey. If comparable labor rates had been charged for developing both sets of data, it is likely that the cost per page unit would have been significantly lower for producing the LTTAs.

theory of operation, schematics and other miscellaneous information would be required for use in troubleshooting those unusual problems not isolated by the FPTA. Also, job guide manuals (JGMs) would be required for non-troubleshooting tasks such as remove, replace, align, and adjust. JGMs and schematics were developed for use with the FPTAs on the AN/APN-147 and AN/ASN-35. These aids cost a total of $32,400 (270 pages at $120 per page). Thus, the total FPTA-JGM package cost a total of $211,531. Theory of operation type information was not developed for use with the systems. There is no data available for estimating the cost of this data, or the cost of a complete FPTA based technical data system for the AN/APN-147 and AN/ASN-35.

A complete system of technical data based on LTTAs would also require two additional types of technical data. Documentation presenting theory of operation and other miscellaneous information would be required for use in troubleshooting those unusual problems not isolated by the LTTA. (Schematics were included in the LTTAs.) Also, some type of documentation would be required for nontroubleshooting tasks such as remove, replace, align, and adjust. This type of data would be presented in JGMs similar to those developed for use with the FPTAs. The JGMs developed for use with the FPTAs were not developed under the specification (MIL-M-38800A) that would be used in the development of the JGMs for use with LTTAs. Thus, the JGMs would differ somewhat in format and may not be based on the same type of thorough task analysis required for development of the JGMs produced for use with the FPTAs. Since JGMs were not made for use with the LTTAs, there is no basis for a direct cost comparison with the JGMs developed for use with the FPTAs. The cost for these JGMs should be no higher than the cost for the FPTA style JGMs and may be somewhat less expensive. Whether the JGMs developed according to MIL-M-38800A would be less expensive would depend on whether a task analysis is required and the thoroughness of the task analysis. Since theory of operation data was not developed for use with the LTTAs, there is no basis for estimating the cost to develop this data. However, there is no reason to believe that the cost for developing theory of operation information for use with LTTAs would differ markedly from the cost to develop the data for use with FPTAs or conventional TOs.

## Section V

## EXPERIMENTAL PROCEDURES

This section describes the procedures used and the results of the experimental evaluation portion of the project. The basic goal of the experimental evaluation was to collect hard data relative to the effectiveness of each type of data for supporting troubleshooting by personnel of varying levels of experience. The experiment was designed to provide answers to questions listed on page 15 (Section 1).

It was desired to evaluate the effectiveness of the three types of data for supporting maintenance personnel with three levels of experience - apprentice technicians with no experience, technicians with less than six months experience on the systems, and technicians with more than six months experience on the system. Technical orders are not designed for independent use by 3-level technicians and 3-level technicians are not expected to be able to troubleshoot on their own using TOs. On the basis of these factors it was determined that it would not be appropriate or necessary to test the apprentice technicians using TOs. As a result of this decision, it was necessary to use two different but similar experimental designs. In the first design, apprentice technicians were tested using two types of data, FPTAs and LTTAs. In the second design, experienced technicians were tested using all three types of data. Data collection for the apprentice subjects was accomplished at Keesler Technical Training Center (KTTC). Data collection for the experienced technicians was accomplished at three Military Airlift Command bases - McChord, Travis, and McGuire. The procedures, test facilities, materials used, and results are described in the following sections.

### TEST FACILITIES AND MATERIALS

Training Materials. To ensure that observed differences in performance were due to the technical data and not due to the technician's not knowing how to use the required test equipment, training programs were developed for 18 pieces of test equipment required to maintain the systems (see Figure 17). The programs were prepared as individual self-taught packages. The instructions are presented in a programmed text format. The time required to complete each program ranges from approximately 15 minutes to 4 hours.

Training programs were also developed to train the technicians to use FPTAs and LTTAs. These programs were prepared in a self-taught, programmed text format similar to that used for the equipment training programs. The programs included practice exercises in which the technicians "performed" several checkout and troubleshooting tasks using the test benches in an inactive (power off) state. The exercises had the dual purpose of developing familiarity with the data and with the test benches.

| | |
|---|---|
| 1 | 410B VTVM Vacuum Tube Voltmeter |
| 2 | 260 VOM Volt Ohmmeter |
| 3 | 545B Oscilloscope |
| 4 | 5245L Electronic Counter and Plug-ins |
| 5 | TV2 Tube Tester |
| 6 | TS-148 Radar Test Set |
| 7 | 803 Differential VTVM |
| 8 | 200CD Audio Oscillator |
| 9 | URM-25D Signal Generator |
| 10 | TS-1100/U Test Set, Transistor |
| 11 | CMA-544 Doppler Simulator |
| 12 | CMA-546 Doppler Generator |
| 13 | 3322-900 Computer Cards Tester |
| 14 | 3322-902 Computer Drives Tester |
| 15 | 3322-905 Navigational Tester |
| 16 | 3322-901 Computer Relay Chassis Tester |
| 17 | SG299B/U Signal Generator |
| 18 | Kay Sweep Generator |

**Figure 17. List of 18 Items of Test Equipment Available for Use with Prime Equipment**

Job Performance Tests. Job performance tests were developed to measure the performance of technicians on 15 troubleshooting problems. The 15 problems were selected to be representative (in terms of difficulty) of problems routinely occurring in the test systems. The problems were selected from the problems used to evaluate the accuracy of the data. They were selected from those problems for which the FPTA and LTTA procedures were found to be accurate. The tests are administered by inserting a malfunction in the system and observing the performance of the technician troubleshooting the problem. Performance is evaluated in terms of whether the problem is solved, time required, and spare parts used. The job performance tests are provided in Volume III of this report.

Attitude Data. Questionnaires were developed to measure the attitudes of the technicians toward each type of data. Basically two types of questionnaires were developed--a mid-experiment questionnaire and a post-experiment questionnaire. The mid-experiment questionnaire was given immediately following the use of one type of data. It asked the technician to rate the data on factors such as ease of understanding and suitability for different levels of maintenance. The post-experiment questionnaire asked the technician to compare the data on the same factors. A rating scale was used to obtain a measure of technician attitudes. A representative scale is shown below:

| | | |
|---|---|---|
| Very difficult to understand and follow | No particular difficulty in following | Very easy to understand and follow |

The technician is asked to indicate by marking the approximate location on the scale which represents his feelings. The scale is scored by measuring the distance of the response from the left side. Thus, the higher the score the more positive the response.

Ancillary Data Collection. In addition to the attitude data collected, additional questionnaires and inventories were administered to collect demographic, aptitude, attitude, and opinion information. These data were not used in the present analysis but were collected for use in future studies and analysis.

Test Facilities. The performance test approach requires dedicated access to the prime equipment for extensive periods of time. It was realized that it would not be possible to obtain sufficient access to test benches at operational bases without causing an unacceptable degree of interference with their mission. To ensure adequate access to the equipment at all test locations, a 40-foot Air Force van was equipped with bench mockups of the AN/APN-147 and AN/ASN-35 to provide a transportable test facility. It was also recognized that it would be extremely difficult to obtain adequate access to C-141 aircraft for use

with the organizational level tests. Thus, a mockup of the C-141 cockpit and the avionics equipment bays of the C-141 was developed and installed in the test van. The cockpit mockup provided a means of simulating the flightline troubleshooting tasks without requiring access to an aircraft. It consists of mockups of all instrument panels in the cockpit. All AN/APN-147 and AN/ASN-35 components are "live" and function in the same manner as in the actual cockpit. All other components on the instrument panels are represented by photographs. The trailer was transported to each test site. At Keesler an additional computer bench and a radar bench, installed in KTTC classrooms and used in technical training, were made available for use in running subjects.

Stopwatches were provided for the experimenters, and for the subject when required. In addition, a standard tool kit including fuses, bulbs, and jumper wires was provided. Certain problems required the use of shorting connectors; these were made available. Additionally, a resolver bridge balancing jig (3173-918) and labeling tags were provided as special materials for problem 11 and an inclinometer was supplied for problem 12. Further detail on the materials required for each problem may be found in Volume III (Test Administrator's Guide) of this report.

## PROCEDURES AT KEESLER TTC

A counterbalanced, repeated measures experimental design was used for the data collection. In this design each subject performed seven problems using FPTAs and seven problems using LTTAs. One-half of the subjects (technicians) performed their seven problems with FPTA first. The other half of the subjects completed their seven LTTA problems first. The job performance tests were used to measure the subjects' performance in terms of successful completion of the problem, spare parts consumed, and time to perform.

<u>Subjects</u>. Eighteen airmen graduates of KTTC Course No. 3ABR32834 served as subjects for this portion of the study. The 21 October and 4 November 1975 graduating classes were used. The airmen were retained at Keesler AFB for a 2-week period beyond course graduation to serve as subjects in the experiment. During the period of involvement in the study, the airmen were exempted from additional duties and were accorded the status of graduates, a designation which led to additional privileges over those typically enjoyed by students.

The subjects were either Airman or Airman First Class. Two of the subjects were female and 16 were male. All subjects were classified as having high aptitude for electronics maintenance (AQE scores of 80 or higher). The training received by the subjects in Course No. 3ABR32834 included 18 weeks of training in basic electronic fundamentals and 18 weeks of theory oriented training on representative sets. Training on the

AN/APN-147 and AN/ASN-35 was received as part of the sets training. This training was 3 weeks in duration. It was primarily theory oriented. Some opportunity for hands-on practice of troubleshooting tasks was provided. However, this practice was very limited.

<u>Procedures.</u> Random assignment procedures were used to determine the order of presentation of problems and the type of data used with each. This was accomplished by first randomly assigning each subject to one of two groups: one group used FPTA first; the other, LTTA first. Each subject was then randomly assigned to 1 of 18 counterbalanced sequences of problem presentation order. Finally, in the subject-problem pairing process, the sequence of exposure to level of maintenance was systematically counterbalanced. The counterbalancing and problem assignment procedures ensured that each problem was performed an equal number of times with each type of data and to control for possible order effects in the experiment.

With the KTTC subjects, 14 of the 15 equipment problems were used. Problem 9 was excluded (see Figure 3, AFHRL-TR-76-74(II), for problem identification). Exclusion of this problem permitted a balanced presentation of problems with the KTTC subjects; seven problems with each type of technical documentation. The 14 problems used were composed of four organizational maintenance level and 10 intermediate maintenance level problems. This division was selected to represent the approximate proportion of organizational and intermediate level maintenance tasks found in the operational environment. There were an equal number of radar and computer problems at the organizational and intermediate levels.

The problem assignment procedure described above was followed in an attempt to control for possible order effects in the experiment.

First access to each graduating class was for a one-half hour period on the day of graduation. During this period, members of the evaluation team were introduced; the purpose of the evaluation was described to the group; a brief tour of the trailer and classroom evaluation areas was conducted; and each class member was given his initial assignment for the following day.

Days one and two of the 2-week period of availability were devoted to test equipment proficiency training. The morning of day three was devoted to either FPTA or LTTA training, depending upon the particular group to which the airman was assigned. The afternoon of day three was devoted either to troubleshooting of problems or to collection of ancillary factor data, again depending upon the group to which the airman was assigned. The remainder of the 2-week period of availability followed predetermined subject schedules (Table 1 and Figures 7, 8, and 9 of Volume II).

At the point of cross-training on the second technical data format, each subject completed an opinion questionnaire on the documentation format he had just used. The subject was then entered into cross-training on the use of the second type of technical data, and exposed to troubleshooting problems with the alternate data type following the schedules referred to above.

At the completion of the second set of experimental problems, the subject was given two opinion questionnaires; the first, concerning the data format he had just finished using; the second, an opinion questionnaire asking him to compare both technical documentation formats.

For each unique troubleshooting problem, the test administrator prepared the equipment by completing the "pretest setup" section of the problem contained in the Test Administrator's Guide (AFHRL-TR-76-74(III)). In addition, the presence of the support material requirements listed in Section IV of the problem was verified. At this point, the subject was brought into the troubleshooting situation. Following the instructions section (Section V) of the guide, the subject was given an information and instructions sheet and asked to read it. Next, he was given a specific instructions sheet and a work order describing the equipment malfunction he was to troubleshoot.

The troubleshooting evaluation was conducted on a one-to-one basis (one test administrator to one subject). The test administrator recorded data on student performance, obtaining measures of time, errors, parts consumed, successful completion of each section (of the troubleshooting procedure), branching followed, correctness of the branching, and degree of success in locating the problem (see AFHRL-TR-76-74(III) Test Administrator's Guide, for sample data recording forms).

Since the adequacy of the document to lead the technician to the equipment component causing the malfunction was the basic issue under evaluation, the test administrator was instructed to answer no procedural questions while the test problem was ongoing.

## PROCEDURES AT MAC BASES

A counterbalanced, repeated measures experimental design similar to that used for the Keesler subjects was used for the experimental subjects. There were two major differences in the designs. The MAC design required the subjects to use all three types of data. Secondly, the experienced design utilized subjects with two levels of experience: those with six months or less experience on the equipment and those with more than six months experience. Each subject completed five problems with each type of data. Data use was counterbalanced so that one-third of the subjects used FPTAs first, one-third used LTTAs first and one-third used TOs first. Performance was measured using the same job performance tests and procedures as used at Keesler TTC.

Subjects. The two remaining subject groups in the design were obtained from Air Force enlisted personnel having the 328X4 AFSC, Avionics Inertial and Radar Navigational Systems Specialist, assigned to operational units of the Military Airlift Command (MAC) and performing maintenance on the AN/ASN-35 and AN/APN-147 systems in C-141A aircraft.

The two groups were classified on the basis of length of experience with the C-141A equipment. Each group has a size of n=18. One group consisted of airmen with six months or less experience on the systems; the second group, airmen with more than six months experience on the systems. All subjects in the two groups were male. A 2-step process was used to select the technicians to serve as subjects at each base. First, a list of personnel in each experience category was obtained from the base. Technicians and alternates were then tentatively selected by a random process. When the evaluation team arrived at the base, final arrangements were made for these technicians to participate in the study. If a selected airman was not available (due to leave, TDY, etc.) an alternate was substituted. Each airman selected as a subject was made available for a 2-week period. During this period, the airmen continued to work their normal shifts and served as subjects for a 4-hour period out of each 8-hour shift.

Procedures. Within each experience group the airmen were randomly assigned to one of three subgroups (six airmen each). One of the three types of technical documents to be initially used was randomly assigned to each group. With the field-experienced group, all 15 equipment problems were used. Thus, each technician was exposed to five problems with each type of technician documentation.

The order of exposure of level of maintenance was systematically counterbalanced. In addition, within each experience group, 18 series of counterbalanced sequences of problems were generated. Each subject was randomly assigned to one of the 18 sequences. Each problem was performed the same number of times with each type of data.

Airmen selected as subjects were initially provided with an introductory letter briefly explaining the nature of the study in which they would be participating. Airmen were then given the pre-experiment questionnaires. Next, airmen were provided with a listing of the test equipment that would be used in the study and asked to estimate their proficiency with each item. At this time, each airman was asked to indicate any test equipment on which he would like to receive refresher training. Experience with the test equipment and observation of KTTC subject interaction with the equipment led to a decision to routinely administer proficiency tests on four items of test equipment, the 260 volt ohmmeter (VOM), the 410B vacuum tube voltmeter (VTVM), the 545B oscilloscope, and the TV2 tube tester. The tests were administered regardless of the level of proficiency expressed by the airmen for these items of test equipment. Remedial training was given to those who failed to demonstrate proficiency on these items of test equipment.

Following any required test equipment training, the airmen were given familiarization training with the new documentation type if their initial exposure was FPTA or LTTA. They then completed the performance tests using that type of data. Airmen initially assigned to TOs went immediately to the job performance tests using that data.

Upon completion of the assigned problems, airmen were given a mid-experiment opinion questionnaire on the documentation just used and then were transitioned to the second set of five problems with the next scheduled documentation type. Upon completion of problem solving with the second documentation type, the airmen were again given a mid-experiment opinion questionnaire on that documentation type and moved to the final problem set with the remaining documentation type. At completion of this last set of five problems, two opinion questionnaires were given. The first covered the document type just used; the second required a comparison of the three types of documentation.

Again, the test administrator followed the instructions contained in the Test Administrator's Guide (AFHRL-TR-76-74(III)) in preparing for each experimental problem. Observation, timing, and scoring procedures were identical to those described for the KTTC group.

## ANALYSIS

Main analysis for both the KTTC and the Military Airlift Command subjects was by means of an analysis of variance of the data collected in a counterbalanced order of presentation, repeated measures design. Following the analysis of variance, significance tests on those comparisons of interest to the study were calculated.

Data collected on the KTTC subjects followed a special case repeated measures design. In each case with this design, the main effect was tested with the factor by subjects' interaction.

Data collected on the Military Airlift Command subjects followed a Winer (1962) Case I, three-factor repeated measures design. Again, following this analysis, significance tests on the comparisons of interest to the study were calculated.

## Section VI

## RESULTS OF EXPERIMENT

### INTRODUCTION

The study results are presented in this section in two separate and distinct forms. This presentation approach was selected in recognition of the complex nature of the data collected. The goal of this, and of any, report of research is to present the results to the reader in the clearest possible manner, and yet provide sufficient detailed support to allow the reader to independently assess the material presented.

Ideally, the research report should permit the reader to establish a level of confidence that he is willing to assign to the results and to the conclusions drawn from the obtained results.

Thus, this section is divided into a proportional analysis presentation which is intended to portray the study results in a clear unencumbered form, and into a statistical analysis presentation which treats the same results, but in a different form. In this latter section, reporting of a result is accompanied with results of the underlying statistical analysis.

The reader interested in obtaining a quick overview of the study results can obtain this information by reading only the proportional analysis presentation.

### PROPORTIONAL ANALYSIS

Keesler Technical Training Center Subjects

Inspection of Figure 18 indicates that more problems were solved with the FPTA at both organizational and intermediate levels of maintenance than with LTTA. Within document types, there was no difference in performance at organizational and intermediate levels when using the FPTA. Use of the LTTA resulted in a difference in performance between organizational level and intermediate level troubleshooting tasks with better performance occurring at the organizational level.

The number of spare parts incorrectly used at both levels of maintenance for each type of documentation is shown in Figure 19. Initial viewing would suggest that use of the FPTA resulted in the use of fewer spare parts. The statistical analysis revealed that this difference in mean number of parts used was not large enough to permit the conclusion that a real difference exists. Unlike this comparison, the comparison of the number of parts incorrectly used at the two levels

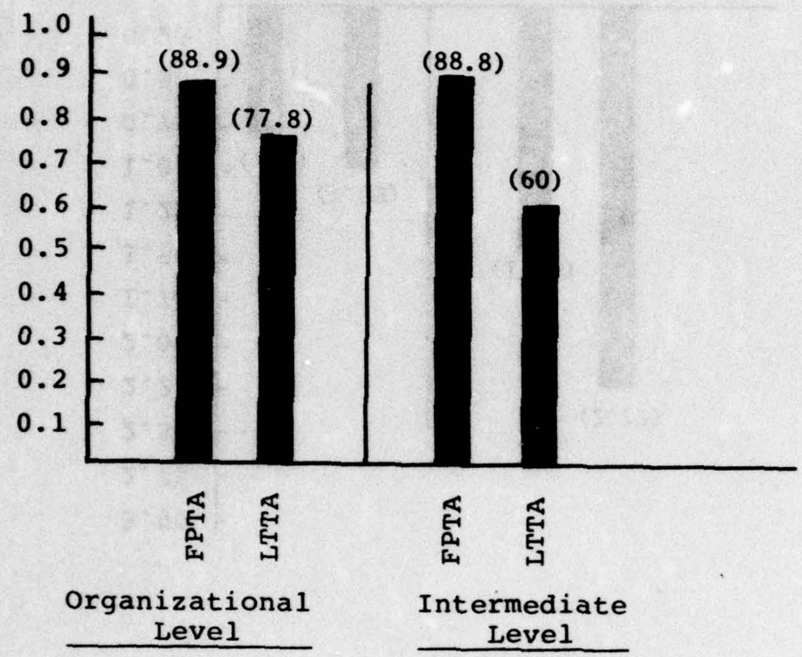


Figure 18. Mean Proportion of Problems Solved by Keesler Subjects by Documentation Type and Level of Maintenance

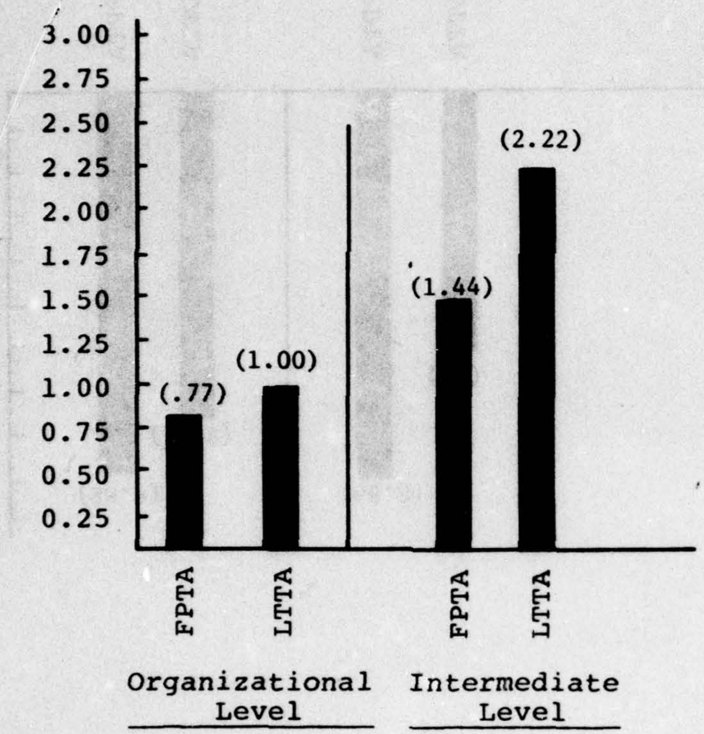


Figure 19. Mean Number of Parts Used by Keesler Subjects by Documentation Type and Level of Maintenance

of maintenance shows a large enough discrepancy to be accepted as a real difference. Fewer parts are used at the organizational level of maintenance. Review of the nature of the troubleshooting tasks at each level of maintenance (organizational and intermediate) would lead one to expect this result.

The mean time required to troubleshoot and repair[3] is shown in Figure 20. It can be seen from the means displayed that at the organizational level of maintenance use of the LTTA as an aid resulted in a shorter mean time than did the FPTA. Insight into the reason for this may be found from review of the verbatim comments of the subjects (see Table A-6 Appendix A). The attitude expressed was that the FPTA forced one into a more lengthy procedure. However, for intermediate maintenance the order was reversed. Here use of the FPTA produced a shorter mean time to repair.

Military Airlift Command Subjects

The mean proportion of problems solved by organizational level of maintenance and by experience level of technicians is depicted in Figure 21. Inspection of the bar charts contained in this figure shows that at the organizational level of maintenance there was effectively no difference in performance for any of the documentation types regardless of the experience levels involved. However, this same result did not occur for intermediate level maintenance. At this level, performance differed for documentation type. For the TO, performance also differed for experience level. Technicians with more than six months system experience performed better with the TO as an aid than did technicians with less than six months experience using the TO.

At the intermediate level of maintenance, performance was better with the FPTA than with the LTTA, regardless of the experience level of the technician. However, this difference in performance is not large enough to be considered a real difference.

Another comparison which may be made from this figure is that of the TO against the proceduralized troubleshooting data presentation (FPTA and LTTA) for intermediate level maintenance. The use of either the FPTA or LTTA resulted in better troubleshooting performance regardless of experience level of the technician. This difference was sufficiently large to be considered a real (not a chance) difference.

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[3] Total time required to troubleshoot and repair a specific problem was obtained for each technician by using the technician's elapsed time on the problem and adding an average time for removal and replacement of each of the parts identified as faulty. Mean times in Figure 20 are the arithmetic means across all technicians.

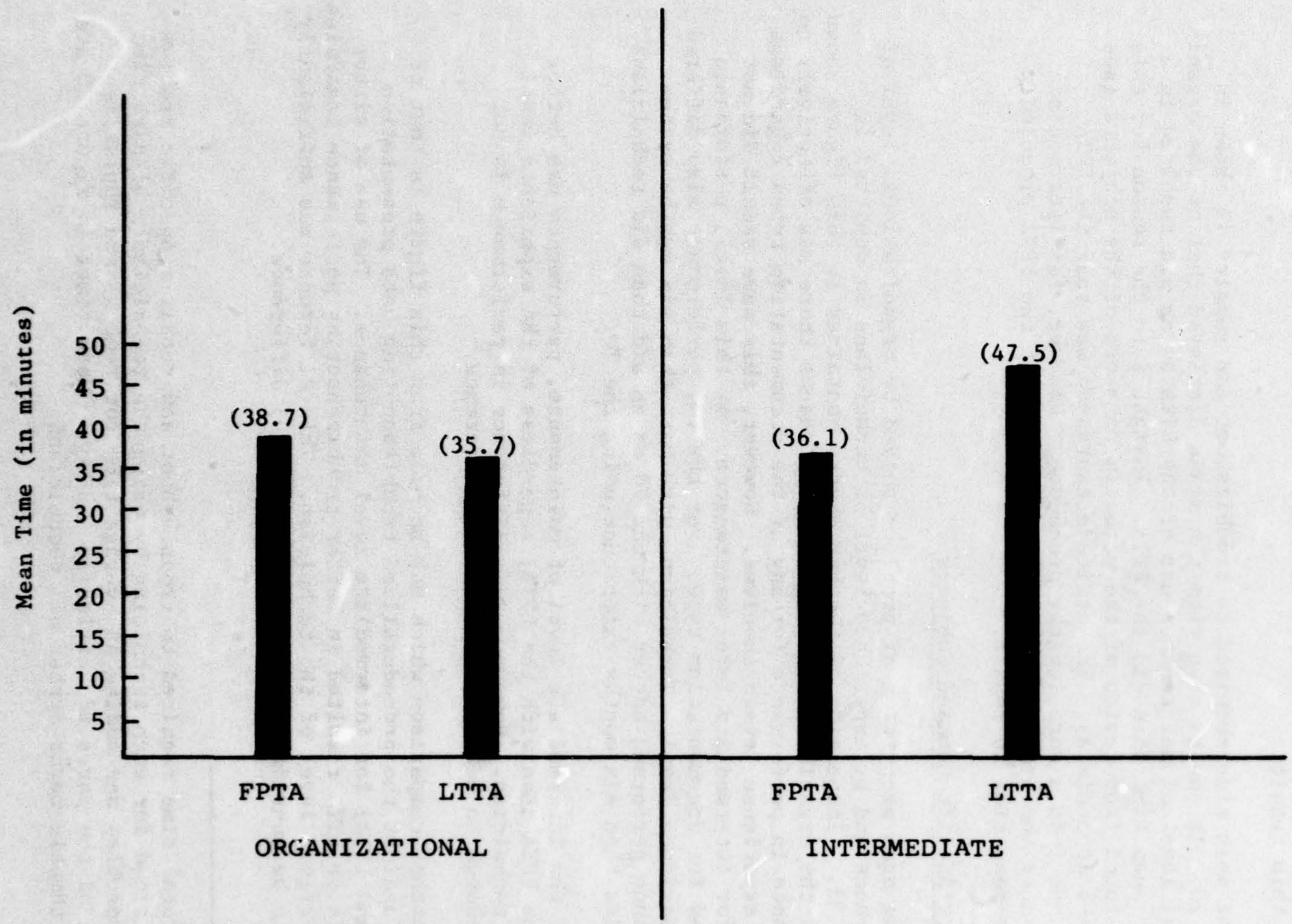


Figure 20. Mean Time to Troubleshoot and Repair by Level of Maintenance and Document Type for Keesler Subjects

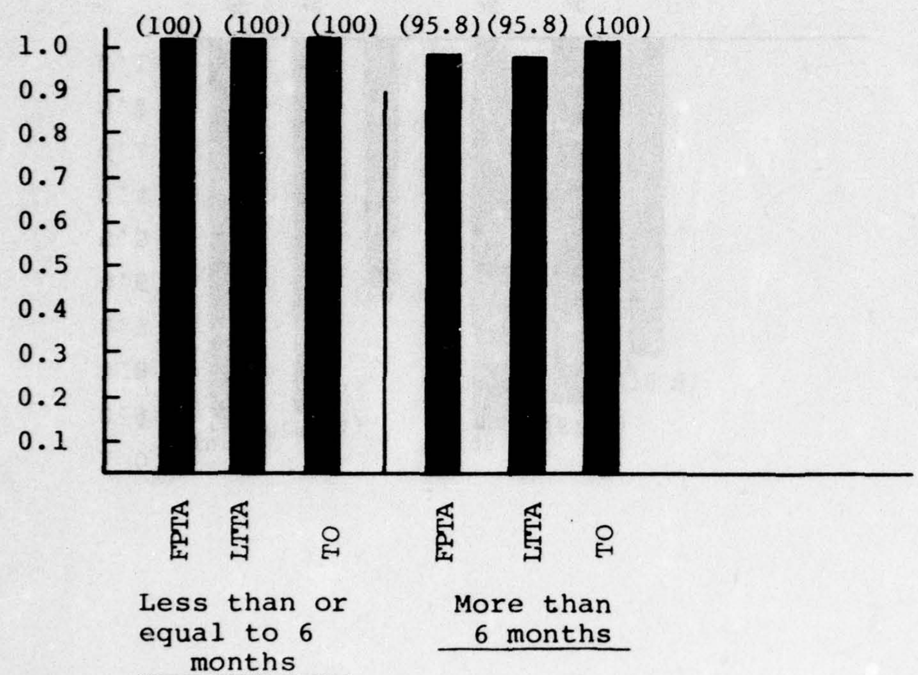


Figure 21. Mean Proportion of Problems Solved by MAC Subjects by Experience Level at the Organizational Level of Maintenance (continued on page 65)

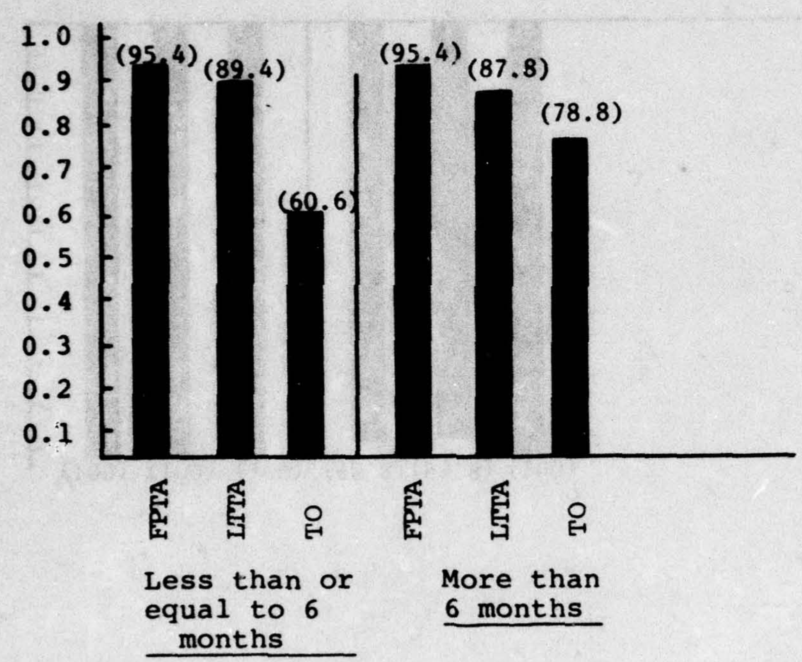


**Figure 21.** Mean Proportion of Problems Solved by MAC Subjects by Experience Level at the Intermediate Level of Maintenance. (Concluded)

The mean number of parts incorrectly used by MAC subjects in solving the troubleshooting problems to which they were exposed is presented in Figure 22. It is apparent from this bar graph that a larger number of parts were used for intermediate level maintenance tasks than for organizational level tasks. This result would be expected due to the nature of the maintenance involved at each level. At the organizational level, the task is to locate the line replaceable unit which has failed. At the intermediate level the task can be to locate either the faulty subassembly or even the faulty component. Thus, one would expect a greater opportunity for identification errors at the intermediate level. This expectation was confirmed by the data.

Examination of Figure 22 also reveals that there is very little difference in the number of spare parts incorrectly replaced using FPTAs and LTTAs at the intermediate level. However, use of the TO resulted in the incorrect use of more spare parts than the use of either FPTA or LTTA.

At the organizational level, performance with each of the types of technical documentation was fairly stable. However, again use of TOs resulted in the highest number of parts being incorrectly used. The difference in mean parts incorrectly used for organizational level troubleshooting was not large enough to be considered a real difference.

The mean time required to troubleshoot and repair using the FPTA, LTTA, or TO as troubleshooting aids at each level of maintenance is depicted in Figure 23. Two interesting patterns are displayed in this figure. First, it can be seen that the pattern of times required at the organizational level was for FPTA to take the longest time, followed by LTTA, with TO requiring the least for the troubleshoot and repair task. This same pattern holds regardless of the experience level involved.

At the intermediate level, the pattern is exactly reversed, with FPTA-guided troubleshoot and repair taking the shortest mean time and TO requiring the longest mean time. Again, LTTA time fell in-between FPTA and TO. This pattern also holds true regardless of the experience level of the subjects.

A significantly greater time to troubleshoot and repair is required when working at the intermediate level. This result is again expected for the same reason given earlier for its appearance in the data depicted in Figure 22. At the intermediate level of maintenance, the technician is working at a finer level of detail and is exposed to more opportunity to incorrectly replace parts than he has to incorrectly replace line replaceable units at the more gross organizational level of maintenance.

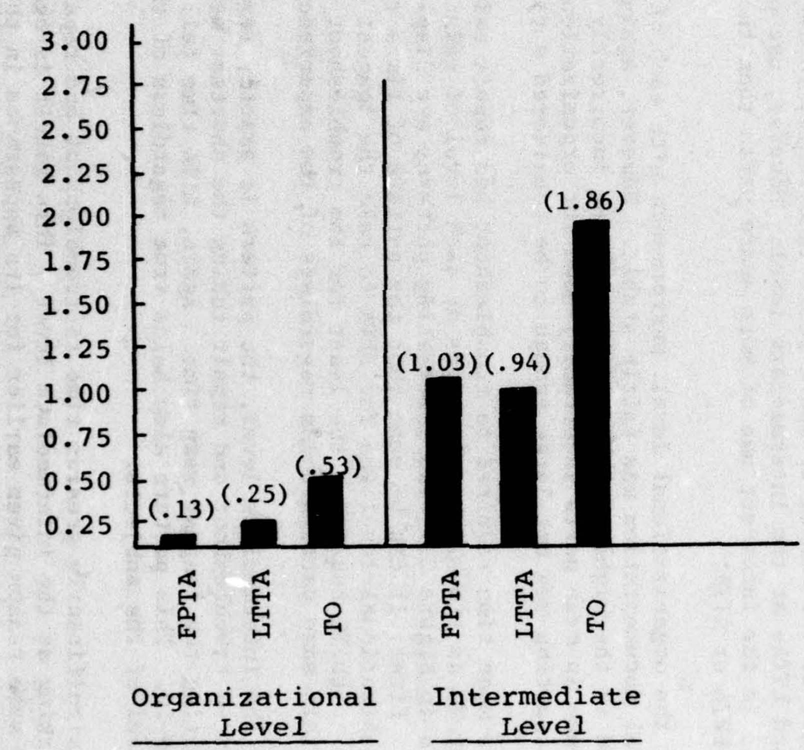


Figure 22. Mean Number of Parts Incorrectly Used by MAC Subjects

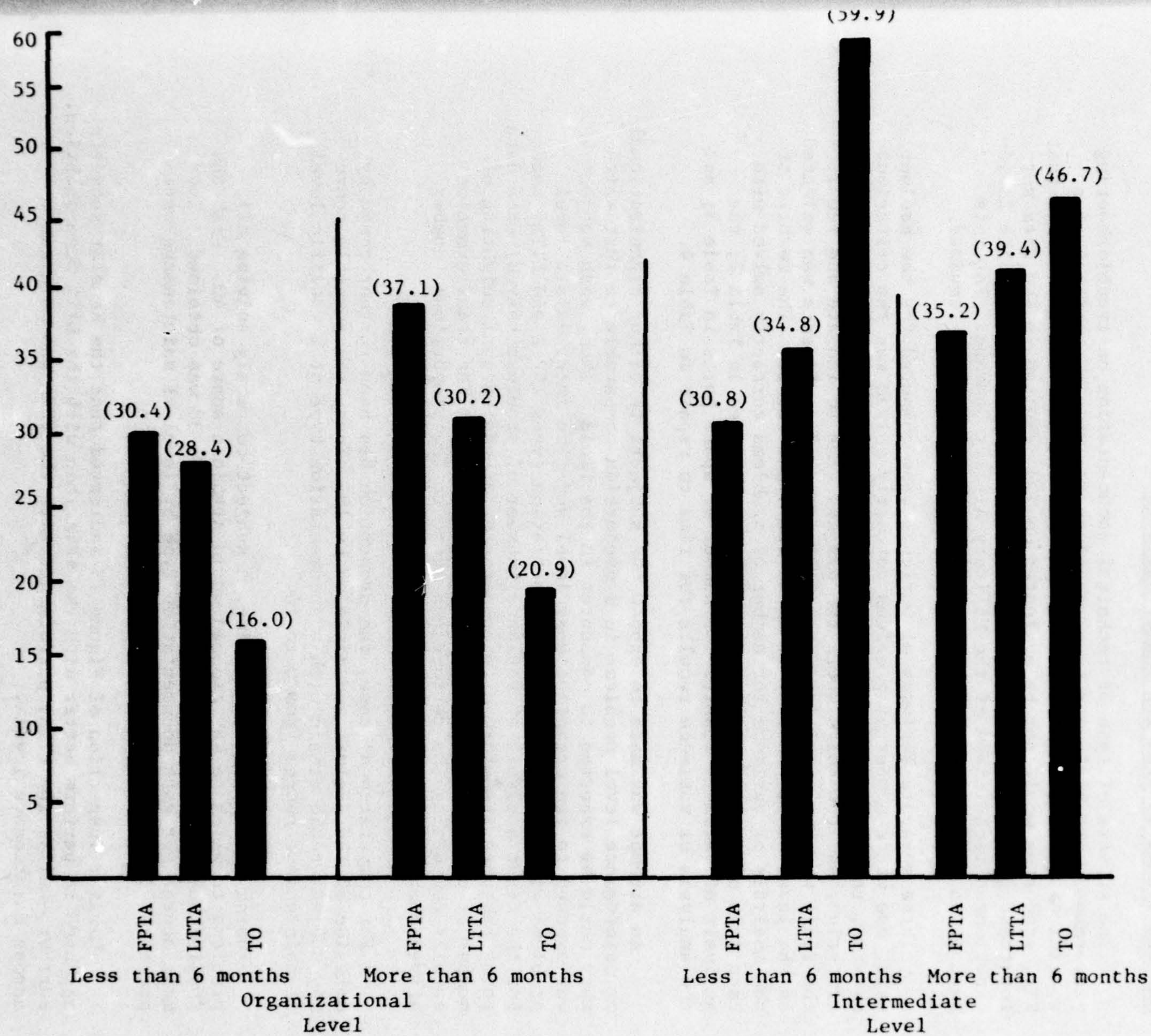


Figure 23. Mean Time to Troubleshoot and Repair at the Level of Maintenance and Document Type

## STATISTICAL ANALYSIS

### Kessler Technical Training Center Subjects

The effects of type of technical documentation on troubleshooting performance were evaluated by means of an analysis of variance of a special case repeated measures design. An administrative decision that KTTC graduates would not be evaluated on TOs resulted in the data set for these graduates being different from that collected with the field-experienced technicians of the Military Airlift Command. For this reason, an independent analysis of the Keesler data was required.

Three separate analyses of variance were computed for the Keelser data, one where number of problems correctly solved was the criterion measure, the second where number of spare parts consumed served as the criterion, and the third where the elapsed time to isolate and repair the fault was the criterion. The 0.05 level of confidence was selected as the level of probability required for significance. The results of the analysis of variance for number of problems correctly solved with each type of technical documentation are presented in Table 2; the analysis of variance results for number of spare parts in Table 3; and the analysis of variance results for time to repair in Table 4.

An attempt was made to expose the subjects to either organizational or maintenance level problems in a proportion comparable to that which they could be expected to encounter in the field. Thus, each subject was exposed to two organizational level and five intermediate level problems with each of the two documentation types (FPTA and LTTA) used. For the first analysis of variance (number of problems solved) each data point has been transformed to compensate for the unequal weighting of number of problems at each level of maintenance. The transformation entails converting the performance score to the proportion: number solved/number presented.

For computational ease, the proportion has been further coded by omission of the decimal and division by 10. Thus, the possible score any subject could attain with a documentation type at a specific level of maintenance ranges from 0 to 10.

Using this system of scoring, a subject correctly solving all problems to which he was exposed would attain a score of 40. With the Keesler subjects, a range of scores from 20 to 38 was obtained. The mean scores for each documentation type by level of maintenance were presented in Figure 18.

Earlier inspection of Figure 18 indicated that the Keesler subjects appeared to perform better with the FPTA than with the LTTA documentation. Further, unlike the LTTA, performance with the FPTA was maintained across maintenance levels.

TABLE 2. SUMMARY TABLE FOR ANALYSIS OF VARIANCE OF KEESLER TECHNICAL TRAINING CENTER SUBJECTS, NUMBER OF PROBLEMS CORRECTLY SOLVED WITH FPTA AND WITH LTTA, OCTOBER 1975

| Source | df | SS | MS | F | P |
|---|---|---|---|---|---|
| Subjects | 17 | 118.61 | | | |
| Maintenance Level | 1 | 14.22 | 14.22 | 4.38 | 0.05<P<0.10 |
| Maintenance Level × Subjects | 17 | 55.28 | 3.25 | | |
| Document Type | 1 | 72.00 | 72.00 | 16.22 | <0.001 |
| Document Type × Subjects | 17 | 75.50 | 4.44 | | |
| Maintenance Level × Document Type | 1 | 14.22 | 14.22 | 3.82 | 0.05<P<0.10 |
| Maintenance Level × Document Type × Subjects | 17 | 63.28 | 3.72 | | |
| TOTAL | 71 | 413.11 | | | |

TABLE 3. SUMMARY TABLE FOR ANALYSIS OF VARIANCE OF KEESLER TECHNICAL TRAINING CENTER SUBJECTS, NUMBER OF SPARE PARTS CONSUMED WITH FPTA AND WITH LTTA, OCTOBER 1975

| Source | df | SS | MS | F | P |
|---|---|---|---|---|---|
| Subjects | 17 | 53.57 | | | |
| Maintenance Level | 1 | 17.01 | 17.01 | 6.54 | $<0.05$ |
| Maintenance Level × Subjects | 17 | 44.24 | 2.60 | | |
| Document Type | 1 | 5.01 | 5.01 | 1.04 | $0.25<P<0.50$ |
| Document Type × Subjects | 17 | 82.24 | 4.84 | | |
| Maintenance Level × Document Type | 1 | 1.13 | 1.13 | $<1$ | |
| Maintenance Level × Document Type × Subjects | 17 | 57.12 | 3.36 | | |
| TOTAL | 71 | 260.32 | | | |

TABLE 4. **KEESLER GRADUATES - MEAN TIME REQUIRED TO TROUBLESHOOT WITH TIME ADJUSTED TO INCLUDE REMOVE AND REPLACE TIME FOR PARTS DESIGNATED BY SUBJECT FOR REPLACEMENT**

| Source | df | SS | MS | F | P |
|---|---|---|---|---|---|
| Subjects | 17 | 1899.07 | 111.71 | | |
| Maintenance Level | 1 | 386.42 | 386.42 | 3.89 | 0.05<P<0.10 |
| Maintenance Level × Subjects | 17 | 1687.26 | 99.25 | | |
| Document Type | 1 | 317.52 | 317.52 | 1.64 | 0.10<P<0.25 |
| Document Type × Subjects | 17 | 2397.59 | 193.98 | | |
| Maintenance Level × Document Type | 1 | 933.12 | 933.12 | 2.40 | 0.05<P<0.10 |
| Maintenance Level × Document Type × Subjects | 17 | 6612.8 | 388.99 | | |
| TOTAL | 71 | 15,133.78 | | | |

That the difference observed by inspection of Figure 18 for documentation type is a real difference is reflected in Table 2. The F ratio for document type achieves a value which is accepted as reflecting a significant difference. Both maintenance level and the interaction of maintenance level with documentation type show a trend toward a significant difference but do not achieve critical value of F required for rejecting the hypothesis of no difference. Inspection of Figure 18 indicates that the trend toward an interaction effect is apparently produced by the failure of performance to remain stable at the intermediate level of maintenance using LTTA documentation. This conclusion is verified by a means of a least significant difference (LSD) analysis (Steel and Torrie, 1960). With the LSD, the critical value required for a significant difference at the 0.05 level of significance is 1.36. Three degrees of freedom for comparison exist. Thus, three comparisons are possible with the data. There is no difference for the mean of performance with FPTA at organizational level versus FPTA at intermediate level comparison; therefore, this comparison can be omitted. The comparison of the means for performance with FPTA at the intermediate level versus LTTA at the organizational level showed no real difference. The difference of means for performance with the LTTA at the organizational versus the intermediate level was 1.7. Thus, this comparison reveals a real difference in performance with influences but, in itself, is not sufficiently strong to result in a significant overall interaction effect between maintenance level and documentation type.

The data presented in Table 3 depict the results of an analysis of variance made for the criterion measure: number of spare parts consumed with each of the documentation types. Inspection of these data reveals that a significant difference exists between performance with each of the two levels of maintenance. The mean number of spare parts used with each document type at each level of maintenance was presented in Figure 19. From inspection of this bar chart, it appeared that the effect of documentation type was consistent across levels of maintenance; further, that the difference between levels of maintenance within each documentation type was greater than the difference between documentation types. These contentions are supported by the values obtained for the F ratios measuring the mean effect of documentation type, the effect of maintenance level, and the interaction effect between maintenance level and documentation type which appear in Table 3.

Summary data on the analysis of variance for mean time required to troubleshoot and repair are presented in Table 4. No effect in this analysis achieved statistical significance. However, the effect of level of maintenance showed a strong trend toward statistical significance. The factors contributing to this trend were graphically presented in Figure 20.

As part of the study plan, each subject was asked to provide his opinion for selected questions about each documentation type after he had finished using that document and to make a comparison of the two

documentation types upon completion of his series of problems. Opinion data were solicited on a Likert-type scale (refer to AFHRL-TR-76-74(II), Appendices A, B, and E-1). For case of comparison, the scale associated with each question was uniform in length (125 mm) and each subject response was recorded as a millimeter value representing the distance of his response from the left (negative valence) side of the scale. Summary information on the results of the opinion questionnaires is contained in Appendix A to this volume. An illustration of the information content is found in the example of the opinion expressed by Keesler subjects toward the use of either the FPTA or LTTA for troubleshooting equipment. The mean score values for the opinions expressed by the Keesler subject group are reflected in Figure 24.

As indicated in this figure, at all levels of maintenance troubleshooting, the FPTA was favored as an aid over the LTTA by the non-experienced Keesler group of subjects. The opinions expressed for FPTA usage ranged from a value of 62 to 125 with a mean value of 110.6 mm. This mean value would represent the consensus opinion of Keesler subjects that the FPTA would be considered extremely useful in this type of maintenance activity. The LTTA did not receive this high an acceptance. The overall values for LTTA ranged from 11 to 125 with an overall value of 84.4 mm. This value can be interpreted as exhibiting the consensus that the LTTA would be of some help but is not favored over the FPTA.

On other questions, the Keesler subjects continued to indicate a favoring of the FPTA over the LTTA. The response favoring use of the FPTA for some level of maintenance was 96 percent. This corresponded to 68 percent for the LTTA. Viewed by level of maintenance: for organizational level troubleshooting, all were of the opinion that FPTA should be used, but only 72 percent favored LTTA; for intermediate level the percentages were 92 and 64. At the organizational level, the opinion favoring FPTA over LTTA was statistically significant (tabular $\chi^2$ = 3.84, calculated $\chi^2 = 5.98$). At the intermediate level no statistically significant difference was obtained (calculated $\chi^2 = 2.04$).

## Military Airlift Command Subjects

The effects of type of technical documentation on troubleshooting performance were evaluated by means of an analysis of variance of a three-factor experiment with repeated measures on the second and third factors. Unlike the Keesler subjects, the MAC subjects were exposed to problems using all three documentation types (FPTA, LTTA, and TO).

As with the Keesler group, three separate analyses of variance were computed for the MAC data. One analysis used the number of problems correctly solved as the criterion measure. The second analysis used the number of spare parts consumed as the criterion. The third analysis used the time to troubleshoot and repair as the criterion. The results for the analysis of variance for number of problems correctly solved with each type of technical documentation are presented in Table 5;

How do you feel about the (FPTA, LTTA) as an aid in troubleshooting the maintenance problems you have just had at the following levels of maintenance?

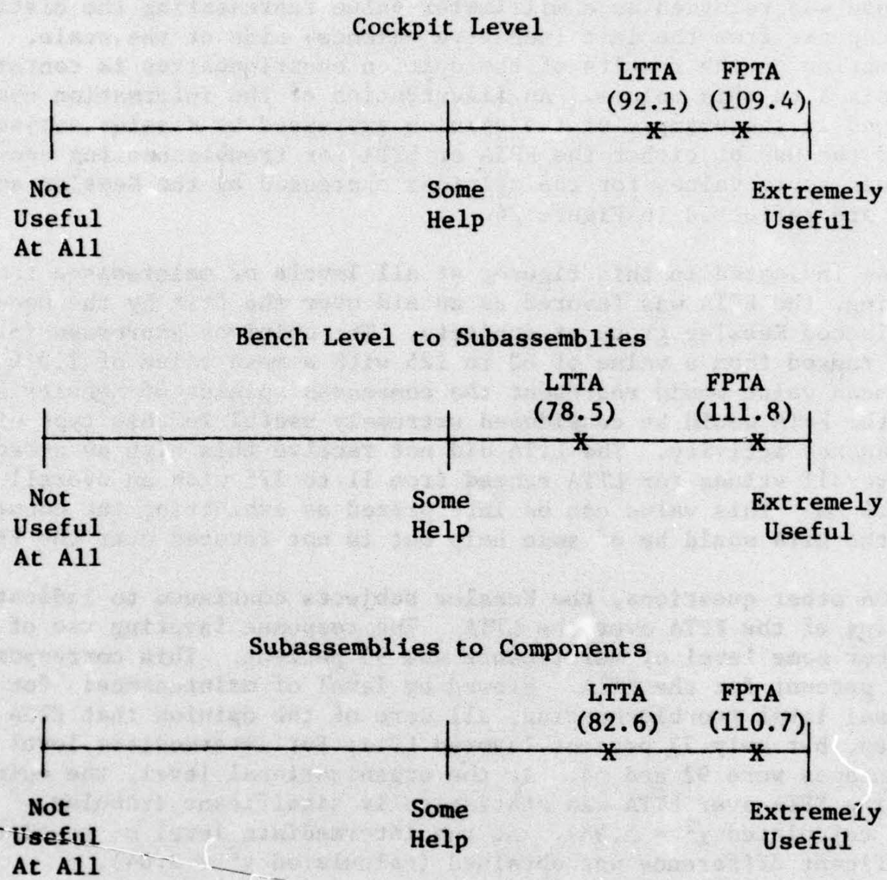


Figure 24. Opinion Results of Keesler Technical Training Center Subjects to Questions about Usefulness of FPTA or LTTA as a Troubleshooting Aid

TABLE 5. SUMMARY TABLE FOR ANALYSIS OF VARIANCE OF MILITARY AIRLIFT COMMAND SUBJECTS, NUMBER OF PROBLEMS CORRECTLY SOLVED WITH FPTA, LTTA AND TO, JANUARY-APRIL 1976

| Source | df | SS | MS | F | P |
|---|---|---|---|---|---|
| **Between Subjects** | 35 | 146.19 | | | |
| Experience Level | 1 | 0.38 | 0.38 | | |
| Subjects Within Groups | 34 | 145.81 | 4.29 | | |
| **Within Subjects** | 180 | 686.79 | | | |
| Technical Data Type | 2 | 57.70 | 28.85 | 12.71 | $<0.01$ |
| Exp. Level × Technical Data | 2 | 15.75 | 7.88 | 3.47 | $<0.05$ |
| Tech. Data × Subjects within Groups | 68 | 154.11 | 2.27 | | |
| Maintenance Level | 1 | 99.36 | 99.36 | 26.57 | $<0.01$ |
| Exp. Level × Maintenance Level | 1 | 11.17 | 11.17 | 2.99 | $0.05<P<0.10$ |
| Main. Level × Subjects within Groups | 34 | 127.01 | 3.74 | | |
| Tech. Data × Main. Level | 2 | 61.48 | 30.74 | 14.10 | $<0.01$ |
| Exp. Level × Tech. Data × Main. Level | 2 | 11.63 | 5.82 | 2.67 | $0.10<P<0.25$ |
| Tech. Data × Main. Level × Subjects within Groups | 68 | 148.58 | 2.18 | | |
| TOTAL | 215 | 832.98 | | | |

the analysis of variance results for number of spare parts consumed in Table 6; and the analysis of variance for time to troubleshoot and repair in Table 7.

Following the procedure used at Keesler, an attempt was made to expose subjects to either organizational or maintenance level problems in proportions comparable to those they encountered in daily operational maintenance activities. One problem was added to the sample set to allow exposure to an equal number of problems with each type of technical documentation. Thus each subject was asked to solve five problems with each documentation type. For the first analysis (number of problems solved) each data point has been transformed to compensate for the unequal weighting of number of problems for each level of maintenance. The transformation entails converting the performance score to the proportion: number solved/number presented. For computational case, the proportion has been further coded by omission of the decimal and division by 10. Thus, subjects could attain scores ranging from 0 to 10 with any documentation type at a specific level of maintenance.

Using this scoring system, a subject correctly solving all problems to which he was exposed would attain a score of 60. With the MAC subjects, a range of scores from 36.6 to 60.0 was obtained. The mean scores for each documentation type by level of maintenance and technician experience level were presented in Figure 21.

The summary of the analysis of variance depicted in Table 5 indicates that four of the effects analyzed were statistically significant. Thus, the effect of type of documentation and of level of troubleshooting maintenance on performance was real. In addition, two interaction effects were present: a strong interaction effect existed between type of documentation being used and the level of troubleshooting maintenance; a less strong but real interaction effect on performance also existed between experience level and type of technical documentation being used.

The effect of level of maintenance on performance is graphically portrayed in Figure B-1 (Appendix B). The mean proportion of problems solved at the organizational level of maintenance was 0.98; the mean proportion of problems for the intermediate level, 0.85. Since only these two levels of maintenance were involved, it is clear that performance at the organizational level of maintenance was significantly better than at the intermediate level. The type of documentation used also significantly affected performance. It can be seen from Figure B-2 that performance was highest with the FPTA, next best with the LTTA and lowest with existing Air Force TOs. The mean proportion of number of problems correctly solved with FPTAs, LTTAs, and TOs were 0.97, 0.92, and 0.84, respectively. Use of the Tukey procedure for multiple comparisons showed that no significant difference in performance existed for the FPTA and the LTTA, but that performance with the TO was significantly lower than for either the FPTA or LTTA. This significance was obtained beyond the 0.01 level.

TABLE 6. SUMMARY TABLE FOR ANALYSIS OF VARIANCE OF MILITARY AIRLIFT COMMAND SUBJECTS, NUMBER OF SPARE PARTS USED WITH FPTA, LTTA AND TO, JANUARY-APRIL 1976

| Source | df | SS | MS | F | P |
|---|---|---|---|---|---|
| Between Subjects | 35 | 71.79 | | | |
| Experience Level | 1 | 2.04 | 2.04 | <1 | |
| Subjects within Groups | 34 | 69.75 | 2.05 | | |
| Within Subjects | 180 | 363.83 | 2.02 | | |
| Technical Data Type | 2 | 17.53 | 8.76 | 6.58 | <0.01 |
| Exp. Level × Technical Data | 2 | 12.25 | 6.12 | 4.60 | <0.05 |
| Tech. Data × Subjects within Groups | 68 | 90.56 | 1.33 | | |
| Maintenance Level | 1 | 51.04 | 51.04 | 26.69 | <0.001 |
| Exp. Level × Main. Level | 1 | 2.45 | 2.45 | 1.28 | 0.25<P<0.50 |
| Main. Level × Subjects within Groups | 34 | 65.01 | 1.91 | | |
| Tech. Data × Main. Level | 2 | 3.86 | 1.93 | 1.19 | 0.25<P<0.05 |
| Exp. Level × Tech. Data × Main. Level | 2 | 10.95 | 5.48 | 3.38 | <0.05 |
| Tech. Data × Main. Level × Subjects within Groups | 68 | 110.18 | 1.62 | | |
| TOTAL | 215 | 435.62 | | | |

TABLE 7. MAC TECHNICIANS - MEAN TIME REQUIRED TO TROUBLESHOOT, ADJUSTED TO INCLUDE REMOVE AND REPLACE TIME FOR PARTS DESIGNATED BY SUBJECT FOR REPLACEMENT, JANUARY - APRIL 1976

| Source | df | SS | MS | F | P |
|---|---|---|---|---|---|
| <u>Between Subjects</u> | 35 | 14,782.3 | | | |
| Experience Level | 1 | 123.8 | 123.8 | <1 | |
| Subjects within Groups | 34 | 14,658.5 | 431.1 | | |
| <u>Within Subjects</u> | 180 | 72,825.9 | | | |
| Technical Data Type | 2 | 315.8 | 157.9 | <1 | |
| Exp. Level × Technical Data | 2 | 927.2 | 463.6 | 1.44 | 0.10<P<0.25 |
| Tech. Data × Subjects within Groups | 68 | 21,893.2 | 322.0 | | |
| Maintenance Level | 1 | 10,540.6 | 10,540.6 | | <0.0005 |
| Exp. Level × Main. Level | 1 | 469.6 | 469.6 | 1.77 | 0.10<P<0.25 |
| Main. Level × Subjects within Groups | 34 | 9,017.0 | 265.2 | | |
| Tech. Data × Main. Level | 2 | 12,426.5 | 6,213.2 | 26.14 | <0.0005 |
| Exp. Level × Tech. Data × Main. Level | 2 | 1,070.3 | 535.2 | 2.25 | 0.10<P<0.25 |
| Tech. Data × Main. Level × Subjects within Groups | 68 | 16,165.7 | 237.7 | | |
| TOTAL | 215 | 87,608.2 | | | |

The interaction effect existing between type of documentation and level of troubleshooting maintenance is graphically depicted in Figure B-3. An absence of interaction would be denoted by the presence of parallel lines. It can be seen that the interaction effect is caused primarily by the influence on performance of the TO, which differs at the two levels of troubleshooting maintenance. Multiple comparisons by means of the Tukey procedure showed the difference in means for FPTA performance was not real. However, the difference in means for the LTTA performance achieved significance at the 0.05 level, and the difference for TO performance was significant at better than 0.01. Thus, performance is generally better at the organizational level and falls off at the intermediate level. With LTTAs, performance at the intermediate level falls off faster than with FPTA, but not as rapidly as with TOs.

The second interaction effect achieving significance in the analysis summarized in Table 5 was that for experience level by type of technical documentation being used. This interaction is portrayed graphically in Figure B-4. From inspection of this figure it would appear that, with the exception of the use of TOs, the low experience group performed better than did the more experienced group. However, the results of the Tukey procedure do not support this contention. There is no real difference between the two experience groups for performance with the FPTA or LTTA documentation types. The difference reflected for performance with TO documentation was real and caused the interaction effect of documentation type and experience level to achieve significance.

To the question of the presence of an interaction effect between type of technical documentation and level of experience for number of problems correctly solved, the data again dictate a positive response. The degree of severity of this interaction is reflected in Table 5. The nature and direction of interaction are depicted in Figure B-4. The Tukey procedure identifies the interaction existing between TOs and experience level as the causal factor for the overall interaction effect.

Another question investigated in this study was whether performance with the three types of technical documentation differed for organizational and intermediate level maintenance troubleshooting activities. Analysis of variance results (Table 7) established the presence of a strong interaction effect for technical data type and level of maintenance. Figure 20 provided graphic insight into the nature of this interaction. Again, the effect contributed by TOs was identified through means of the Tukey procedure as being the causal agent.

The analysis of variance summary for number of spare parts used presented in Table 6 shows two main effects and two interaction effects achieve levels of statistical significance causing the hypothesis of no difference to be rejected. Type of technical documentation and level of maintenance troubleshooting are the significant main effects.

A significant interaction exists for experience level by type of technical documentation and for experience level by type of technical documentation by maintenance level. Graphic representation of these effects is presented in Figures B-5, B-6, B-7, and B-8. The three-way interaction for experience level, type of technical documentation, and level of maintenance troubleshooting is depicted in Figure B-6. Two factors contributing to the significant interaction are quickly discernible. First, parts usage by experience level reverses for LTTA and TO when compared against FPTA. With FPTA the more experienced used more parts. Second, the number of parts used by level of maintenance shows a wider disparity for TOs than for either FPTAs or LTTAs. The effect of experience is most constant with LTTAs.

A summary of the analysis of effects of each of the document types as an aid to troubleshooting in terms of time to locate and repair a fault is presented as Table 7. Inspection of this table shows that maintenance level and the interaction of maintenance level and technical data were highly statistically significant. Further, a trend can be seen for experience level to interact with the other main factors of the experiment: technical data and level of maintenance. However, though exhibiting a strong tendency for an interaction effect, the combination effect of any other factor with experience level was not strong enough to achieve statistical significance.

The two-way interaction between experience level and type of technical documentation used is clearly portrayed in Figure B-8. Again, the reversal of number of parts used by experienced technicians when using FPTAs is clearly evidenced.

The significant difference existing among types of technical documentation for number of parts used in troubleshooting is clearly produced by the effect of TOs. This effect is displayed in Figure B-7.

The significant difference existing between levels of maintenance troubleshooting was an expected difference due to the nature of the troubleshooting tasks involved at each level of maintenance. The potential for parts replacement is much greater with intermediate maintenance level troubleshooting tasks. This relationship of parts replaced to level of maintenance troubleshooting is depicted in Figure B-5.

In this study, an answer was sought to the question of whether quality of performance with the three types of documentation depends upon the experience level of the technician. The pattern of differences reflected in Figure B-4 provides evidence for an answer that, with the exception of TOs, the quality of performance did not depend upon experience level.

Another question posed was whether FPTA performance differed from LTTA performance, and if both FPTA and LTTA performance were different from TO performance. The use of the Tukey procedure on the data

portrayed in Figure B-2 provides evidence for a positive answer to the question of whether or not performance is different with the TO than it is for either the FPTA or LTTA. No real difference existed for performance with the FPTA and LTTA.

Summary information on the opinions expressed by field-experienced technicians toward the use of the FPTA, LTTA, and TO is contained in Appendix A to this volume. Responses to an opinion question concerning the use of the FPTA, the LTTA, or the TO for intermediate level troubleshooting of equipment were fitted along a Likert-type scale 125 mm in length (shown in Figure 25). Possible range of scores was from 0 (strong negative valence to 125 (strong positive valence). For this question the overall responses of field technicians with respect to FPTAs ranged from 17 to 125, with a mean response of 92.7 mm. The overall range for LTTAs was 0 to 125 with a mean response of 81.6 mm. For TOs the opinion data ranged overall from 9 to 117 with a mean response of 58.0 mm. The mean score values expressed by the MAC subjects about the usefulness of the FPTA, LTTA, and TO are reflected in Figure 25. Clearly, for this particular maintenance troubleshooting activity, field-experienced technicians favored either FPTAs or LTTAs over the present Air Force TO.

In addition to the technician's opinion about the use of FPTA, LTTA or TO documentation, each technician was asked to give his opinion with respect to the ease of understanding of the document types. Scores ranged from 0 to 125 mm. The mean response for each type of documentation was as follows: FPTA--89.3 mm, LTTA--76.0 mm, TO--43.3 mm. The mean responses are located along a scale line in Figure 26.

How do you feel about the (FPTA, LTTA, TO) as an aid in troubleshooting the maintenance problems you have just had at the following levels of maintenance?

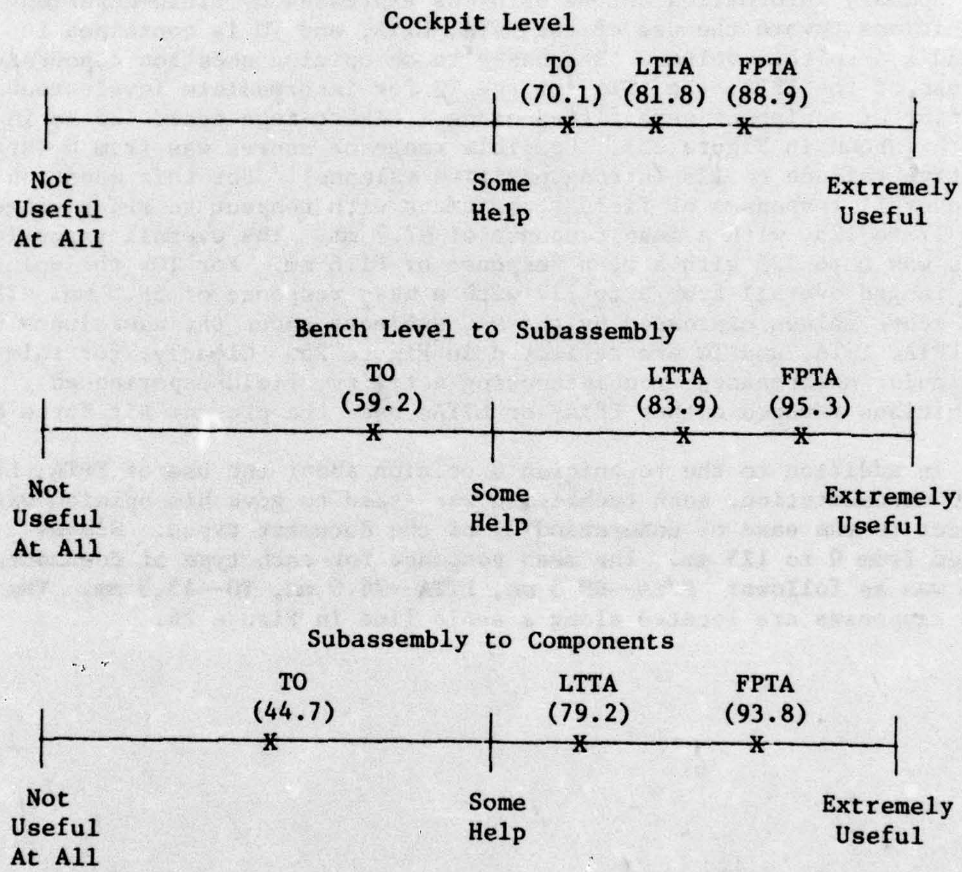


Figure 25. Opinion Results of MAC Subjects to Questions About the Usefulness of FPTA, LTTA or TO as a Troubleshooting Aid

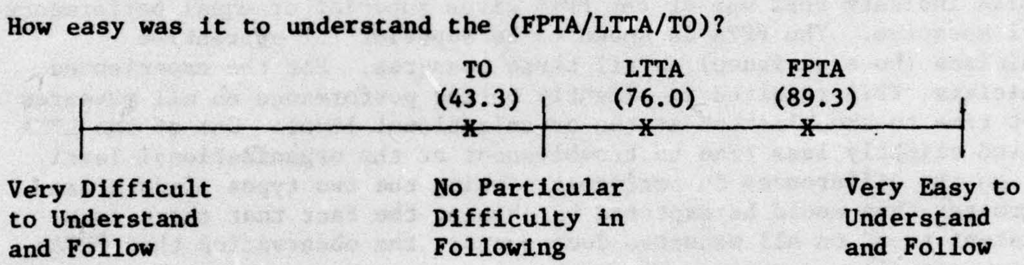


Figure 26. Mean Response for Ease of Understanding for Each Type of Technical Documentation of MAC Subjects

Section VII

# DISCUSSION

The results of the experimental evaluation clearly demonstrate that the use of the proceduralized troubleshooting approach led to significantly better troubleshooting than the use of the TO. This finding is consistent for two of the three measures: proportion of problems solved and spares consumed. The only exception was for time to troubleshoot at the organizational level. This is apparently due to the high degree of competence of the technicians who can frequently recognize the cause of the trouble after only a few checks. Time to troubleshoot was significantly greater, however, for the TO for intermediate level troubleshooting.

Comparisons of performance using the FPTA with performance using the LTTA indicate that use of the FPTA gives superior or equal performance on all measures. The FPTA is shown to be superior for apprentice technicians (no experience) on all three measures. For the experienced technicians, FPTA resulted in slightly better performance on all measures except time to troubleshoot at the organizational level. Use of the LTTA required slightly less time to troubleshoot at the organizational level. Although the differences in performance using the two types of data are not greater than could be expected by chance, the fact that there is a consistent trend on all measures does support the observation that FPTAs lead to generally superior performance.

A somewhat unexpected finding was the essentially equal performance regardless of experience level of the technicians for troubleshooting with FPTAs at both levels of maintenance troubleshooting. A wider discrepancy was exhibited for performance with both LTTA and TO documentation when comparing organizational level against intermediate level troubleshooting. Casual observations of the experimenters during the running of this controlled experiment would have suggested that field-experienced technicians rejected the FPTA documentation in favor of the LTTA for the reason that it did not make allowances for the attained skills and knowledges of the user. This contention is not supported by the data. Both objective performance data and subjective opinion data of the technicians provide unqualified support for the use of the FPTA as the most favored of the three types of technical documentation.

One of the anticipated advantages of FPTAs and LTTAs is a reduction in spare parts consumption. The results of the experiment confirm this expectation. Significantly fewer parts were used with both FPTA and LTTA than with the TO. Nearly twice as many good parts were unnecessarily replaced when the TO was used than when FPTAs and LTTAs were used. These findings suggest that significant savings in spare parts could result from application of the FPTA and LTTA technology to operational systems.

Another important observation from the experimental data is that the performance of apprentice technicians using FPTAs and LTTAs approaches the performance of both categories of experienced personnel. Performance of the Keesler subjects with FPTAs was essentially the same as the performance of the experienced technicians with FPTAs and better than their performance with the TO. The performance of the Keesler subjects with the LTTA approaches the performance of the experienced technicians with the LTTA but is somewhat lower. However, the performance of the Keesler subjects with the LTTA is equal to the performance of the less than six month group with TOs and approaches the performance of the over six month group with the TO. The significance of this observation is that the use of FPTAs may make it possible for new technical school graduates to become effective almost immediately upon assignment to a maintenance organization. The use of LTTAs could have a similar impact. However, it is likely that more OJT would be required before performance could reach the same level. This benefit could have a significant impact on the operation of units with many 3-skill level personnel assigned.

The accuracy analysis indicates that there is relatively little difference in the technical accuracy and completeness of the data produced under the rigid specification used for developing the FPTAs and the less rigid specification used for developing the LTTAs. Since the procedures specified in the FPTA specification are largely required to ensure technical accuracy, one might be tempted to conclude that the FPTA specifications are not valid. However, this would be a hasty conclusion. It would be incorrect to conclude that the tasks specified in the FPTA specification are not necessary. The tasks must be performed in some manner to develop both FPTAs and LTTAs. The question is whether the tasks should be accomplished in a specific way or should be accomplished using procedures selected by the contractor and approved and supervised by the procuring agency. The same basic tasks were required (by the contract but not by MIL-M-38800A) in the development of the LTTA prepared in this project as were required by the FPTA. The difference was that the LTTA contractor was given freedom in determining how they were done and the procuring agency was concerned only with the outcome.

The previous analysis would suggest that an appropriate approach would be to require that certain tasks be performed in the development of the aids but that the procedures for performing them not be rigidly specified. The required procedures would require a task analysis (including task identification, training/ technical data trade-off, action tree development, etc.) preparation of the data in a specified format and validation. This approach is essentially the same as that used in developing the LTTAs procured in this study.

Any new technical order has many errors. The FPTAs and LTTAs do not have any more errors than would be expected in a new technical order. However, the nature of proceduralized data requires that they be much more accurate, nearly perfect. This is due to the fact that the technician is following a predetermined strategy that he does not

necessarily understand or know where it is leading. Thus, if a typographical error causes him to go to page 16 instead of page 14, he would become hopelessly lost. Time and financial constraints did not permit complete verification of the FPTAs and LTTAs. As a result they have more errors in them than would be permissible for use in an operational environment. Further verification would be required before the data could be used operationally. This situation provides an opportunity to emphasize that a thorough validation and verification is essential for the development of either FPTAs or LTTAs. It is strongly recommended that a thorough validation and verification be required for all FPTA and LTTA procurements.

The cost comparison clearly indicates that the FPTAs are more expensive to develop than LTTAs. This appears to be due largely to the fact that nearly twice as many pages were required for the FPTAs than for the LTTAs. The additional pages were due largely to the requirements for extensive use of illustrations and the increased level of detail. It is believed that these two factors account for a large portion of the generally better performance with the FPTA, especially with the inexperienced apprentice technicians. This belief is based on observations of technicians using the LTTA. The most apparent causes of failure were inability to locate referenced parts and insufficient detail in the instructions to permit the less experienced technicians to complete the step. It appears then that any decision regarding which type of data to procure requires a cost trade-off analysis. The trade-off must answer the question "Is the additional benefit worth the cost?" The answer depends upon several factors including: the skills of the intended user, the expected cost savings resulting from more efficient maintenance (reduced maintenance times and reduced spares consumption), and the impact of each data type on training.

The present study has provided valuable information relative to the comparative costs and cost benefits of FPTAs, LTTAs, and TOs. However, the type of information required to adequately compare costs is beyond the scope of the project. It has not adequately compared the costs of TOs and the new types of data. To satisfactorily answer this question, it would be necessary to obtain specific information on the costs to develop FPTAs, LTTAs, and TOs on the same (or very similar) system from the same data base (preferably the engineering analysis) by the same or very similar contractors (in terms of experience, labor rates, etc.). This type of data would provide valid input for a second needed study, a life cycle cost analysis. The life cycle cost analysis is needed to evaluate the impact of FPTAs and LTTAs on maintenance costs. Such a study would provide a means of estimating the cost savings due to reduced spare parts consumption and training requirements.

The demonstration that apprentice technicians can troubleshoot at a level of effectiveness equal to or better than the performance of experienced technicians suggests that significant personnel and training savings could result from the application of the FPTA and LTTA

technologies. As minimum, apprentice technicians should require less OJT and be effective workers earlier in their careers. The performance of the apprentice technicians in this study also suggests that the use of FPTAs and LTTAs could make it feasible to reduce the length of Air Training Command resident training. For example, use of FPTAs or LTTAs might make it possible to eliminate sets training (training on representative sets of Air Force equipment) from the resident course. This could significantly reduce the length of the training course and thereby reduce training costs. Further research is needed to study and evaluate the potential of FPTAs and LTTAs for reducing training.

## Section VIII

## CONCLUSIONS AND RECOMMENDATIONS

The analysis of the data collected in the study indicates that, given technically accurate FPTAs and LTTAs of high quality, the following conclusions may be made:

1. Apprentice electronics technicians with no field experience are able to troubleshoot moderately complex electronic systems effectively using FPTAs and LTTAs. These technicians are able to troubleshoot more effectively with FPTAs than LTTAs.

2. Technicians with more than six months experience on moderately complex electronic systems are able to troubleshoot more effectively with FPTAs or LTTAs than with the standard TO at the intermediate level of maintenance. These technicians are able to troubleshoot equally well with FPTAs, LTTAs, and TOs at the organizational level of maintenance.

3. Technicians with some experience (but less than six months) on moderately complex electronic systems are able to troubleshoot more effectively using FPTAs or LTTAs than with the standard TO at the intermediate level of maintenance. These technicians are able to troubleshoot equally well with FPTAs, LTTAs, and TOs at the organizational level.

4. Apprentice technicians with no field experience using FPTAs are able to troubleshoot as effectively at the intermediate level as experienced technicians (with more than six months experience) using standard TOs. The apprentice technicians using either FPTAs or LTTAs are able to troubleshoot as effectively or more effectively at the intermediate level than technicians with some experience (less than six months) using standard TOs.

5. The use of FPTAs or LTTAs results in significantly fewer "good" parts being replaced unnecessarily than when standard technical orders are used. Use of FPTAs or LTTAs at the intermediate maintenance level in an operational environment could result in significant cost savings due to reduced spare parts consumption.

6. For experienced technicians, troubleshooting at the organizational level is performed the most rapidly when the TO is used. However, at the intermediate level, troubleshooting is performed significantly faster when either the FPTA or LTTA is used instead of the standard TO.

7. Experienced technicians believe that the TO is more difficult to understand than either the FPTA or LTTA.

8. Experienced technicians prefer either the FPTA or LTTA over the standard TO for use in troubleshooting at all levels of complexity examined (flight line, "black box" to sub-assembly to piece part). FPTA is preferred over LTTA.

9. There is insufficient data available on the costs of FPTAs, LTTAs and TOs to permit an adequate cost comparison. Further research is needed to determine the costs of producing each type of data. The necessary data could most efficiently be collected when processing FPTAs or LTTAs for operational use with an Air Force system.

10. Although the present study was limited to electronic maintenance, it is highly probable that similar results would be obtained in other maintenance areas. However, application of the technology to other areas is necessary before a firm conclusion can be made.

As a result of this research effort, the following recommendations are made:

1. Consideration should be given to the development of FPTAs or LTTAs for any future technical order improvement program. It is especially important that these types of data be considered for intermediate level maintenance where the benefits are likely to be the greatest. The determination of which type of data should be developed should be based on an analysis of the capabilities of the intended user, type and complexity of the equipment, and the maintenance concept for the system.

2. Proceduralized troubleshooting data (FPTA, LTTA, or hybrid) should be developed for one or more sub-systems of a modern Air Force weapons system. Development of proceduralized data for such a system would provide the opportunity to obtain data on the costs of developing the data, effectiveness of the data in an operational environment, and the problems associated with the use of the data (user acceptance, updating, etc.). It is suggested that a sub-system from the F-15 be selected as the test system. An F-15 system would provide a test of the proceduralized troubleshooting technology on "state of the art" equipment. Also, since the aircraft is operational, it would be possible to collect baseline data on maintenance of the system with conventional TOs. If this recommendation is adopted, it is also suggested that the developer be required to maintain detailed records relative to the cost of developing the data.

3. Considering the importance of FPTAs and LTTAs being technically accurate, it is essential that the development process include a thorough validation and verification. It is strongly recommended that the actual equipment be provided to the contractor on a dedicated basis for use in the task analysis validation and verification.

4. Additional analyses of the costs and cost benefits of FPTAs and LTTAs should be made. The analyses should attempt to estimate the potential savings in spare parts and training resulting from the use of FPTAs and LTTAs.

5. Studies should be conducted to determine the potential impact of FPTAs and LTTAs on the training and personnel systems for reducing the life cycle costs of hardware systems.

6. Strong consideration should be given to the modification of the LTTA format to include more of the procedural material found in the FPTA (e.g., more graphics and location call-outs). The resultant documentation format would capitalize on the advantages observed in this study for both the FPTA and the LTTA.

## References


Foley, J. P., Jr. Description and results of the Air Force research and development program for the improvement of maintenance efficiency. AFHRL-TR-72-72, AD 771 000. Wright-Patterson AFB, OH: Air Force Human Resources Laboratory, November 1973.

Joyce, R. P., Chenzoff, A. P., Mulligan, J. F. and Mallory, W. J. Fully proceduralized job performance aids: Volume I Draft specification for organizational and intermediate maintenance. AFHRL-TR-73-43(I) AD 775 702. Wright-Patterson AFB, OH: Air Force Human Resources Laboratory, December 1973.

MIL-M-24100B. Military specification, manuals technical: Functionally oriented maintenance manuals (FOMM) for equipment and systems. September 1973.

MIL-M-38799. Military specification, manuals technical: Schematic block diagrams (SBD), maintenance dependency charts (MDC). August 1971.

MIL-M-38800A. Military specification, manuals technical: Organizational maintenance instructions (for aircraft, missiles, and non-munition accessories). September 1974.

Potter, N. R. Evaluation of three types of technical data for troubleshooting: Volume II - Methodology for Field Evaluation. AFHRL-TR-76-75-(II), Wright-Patterson AFB, OH: Air Force Human Resources Laboratory. November 1976.

Potter, N. R., Hubbert, P. R., Landolfi, J. V., Rice, D. L., and Kearns, N. H. Evaluation of three types of technical data for troubleshooting: Volume III - Test administrator's guide. AFHRL-TR-76-74(III), Wright-Patterson AFB, OH: Air Force Human Resources Laboratory. October 1976. AD-A031 850.

Steel, R. D. G. and Torrie, J. H. Principles and procedures of statistics. McGraw-Hill, New York, 1960.

Winer, B. H. Statistical principles in experimental design. McGraw-Hill, New York, 1962.

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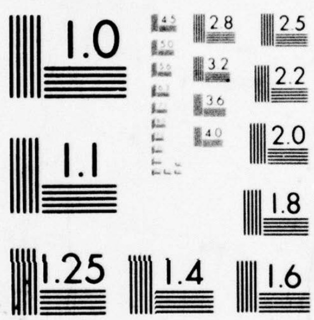


MICROCOPY RESOLUTION TEST CHART
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## APPENDIX A

**SUMMARY DATA AND VERBATIM COMMENTS OF KTTC AND MAC SUBJECTS TO QUESTIONS ABOUT THE FPTA, LTTA, AND TO**

TABLE A-1. MEAN RATINGS* ASSIGNED TO FPTA AND LTTA BY KEESLER SUBJECTS FOR USE AS AN AID IN TROUBLESHOOTING AT DIFFERENT LEVELS OF MAINTENANCE

| | Cockpit | Bench Level to Subassembly | Subassembly to Component | Overall Rating |
|---|---|---|---|---|
| FPTA | 109.4 | 111.8 | 110.7 | 110.6 |
| LTTA | 92.1 | 78.5 | 82.6 | 84.4 |

* where rating assigned can range from 0-125, with 125 the highest favorable rating

TABLE A-2. MEAN RATINGS* ASSIGNED TO FPTA, LTTA, AND TO by MAC SUBJECTS FOR USE AS AN AID IN TROUBLESHOOTING AT DIFFERENT LEVELS OF MAINTENANCE

| | Cockpit | Bench Level to Subassembly | Subassembly to Component | Overall Rating |
|---|---|---|---|---|
| FPTA | 88.9 | 95.3 | 93.8 | 92.7 |
| LTTA | 81.8 | 83.9 | 79.2 | 81.6 |
| TO | 70.1 | 59.2 | 44.7 | 58.0 |

* where rating assigned can vary from 0 - 125, with 125 the highest favorable rating

TABLE A-3. RESPONSE OF KEESLER SUBJECTS TO THE QUESTION: WOULD YOU LIKE TO SEE THE AIR FORCE USE FPTA OR LTTA DOCUMENTATION FOR ANY OF THE FOLLOWING LEVELS OF TROUBLESHOOTING

| | FPTA | | LTTA | |
|---|---|---|---|---|
| | Org. | Int. | Org. | Int. |
| YES | 25 | 23 | 18 | 16 |
| NO | 0 | 2 | 7 | 9 |

TABLE A-4. RESPONSE OF MAC TECHNICIANS* TO THE QUESTION: WOULD YOU LIKE TO SEE THE AIR FORCE USE FPTA OR LTTA DOCUMENTATION FOR ANY OF THE FOLLOWING LEVELS OF TROUBLESHOOTING

| | FPTA | | LTTA | |
|---|---|---|---|---|
| | Org. | Int. | Org. | Int. |
| YES | 32 | 44 | 31 | 32 |
| NO | 14 | 2 | 15 | 14 |

* Responses are tabulated for all 46 technicians on whom data was collected. The composition of the 46 technicians was as follows:

| | |
|---|---|
| used as subjects | 36 |
| dropped from study | 1 |
| extra to study | 1 |
| radar transition technicians | 8 |
| | 46 |

TABLE A-5. MEAN RATING EACH DOCUMENT TYPE ON EASE OF UNDERSTANDING (WHERE INDIVIDUAL RATING CAN RANGE FROM 0 - 125 AND 125 INDICATES GREATEST EASE)

| | Keesler Subjects | MAC Subjects |
|---|---|---|
| FPTA | 105.7 | 89.6 |
| LTTA | 74.8 | 77.0 |
| TO | | 43.6 |

TABLE A-6. VERBATIM COMMENTS OF SUBJECTS TO THE QUESTION: WHAT TROUBLESHOOTING METHOD WAS THE EASIEST TO FOLLOW? WHY?

MAC SUBJECTS

FPTA

Because everything was in one book and in sequence of what you would want next.

They took you step by step through the troubleshooting, which is helpful for a beginner on the system.

They had best steps. At bench level and subassembly checks.

Direct referencing to the particular malfunction was stated at each step.

Step by step - geared towards each and every operation.

Because everything has been taken in careful account for the tests.

Their sequence of procedure was logical and easy to understand. They provided sufficient information to locate most items properly and quickly and enabled technician to find the checkout procedure and troubleshooting steps.

It was highly specific and irritatingly like being "programmed". Still effective and a well written text.

Because you can find test hook-ups and diagrams on the pages you are working.

It was easy to find the problem but would take longer on a real flightline.

It does not assume that the person reading it knows anything about the system under check.

Logical, complete, easy to find everything and consistent.

Told you exactly what to do and not to do. Led you directly to the malfunction.

All controls, test points, etc. were numbered, making items easier to locate. Following troubleshooting procedures was just a bit easier than LTTA's.

TABLE 6. Continued

LTTA

The method had a logical sequence for troubleshooting.

Because of the go-no-go and use of the good points of the standard TO such as schematic.

It provided the most help with least confusion.

No long lengthy reading to find out what to do next and a person's skill can help him even more.

It was a logical, computer-like procedure.

Logic trees.

The block diagrams are easier to use.

LTTA's give step - step sequence - unable to get lost.

The LTTA gives a "go-no-go" type of procedure. It is very systematic and gives you exact instruction.

Very good - the middle between our old TOs and the new style FPTA. The best of both - more easily accepted into Air Force society now. Lean more towards a knowledge of the system and test equipment to work properly.

TO

(No selections as easiest method)

KEESLER SUBJECTS

FPTA

More detail.

Explains everything, no thought involved.

All necessary information was there in the book as to test equipment set up to where to plug in wires.

Because it told you more of what you have to do and look for.

Easier to understand

TABLE 6. Concluded

Keesler Subjects - FPTA

More information, procedure is "straight-forward"; well defined.

They were more detailed (the steps) which made it hard to make a mistake in a certain procedure.

Because it explains things simple enough that an inexperienced person can understand.

Set up with step by step procedures like a report outline.

More detailed explanations. Very easy to understand and follow.

It tells how to set up equipment and exactly what it should read. It gives detailed information for finding whatever you need to find.

All the diagrams and pictures are right there on the same page as the procedures.

More diagrams.

<u>LTTA</u>

To the point more.

TABLE A-7. TABULATION OF MOST FREQUENT RESPONSES TO THE QUESTIONS INDICATED

**What do you feel are problems with the FPTA?**

| | |
|---|---|
| Unpractical for organizational level | 5 |
| No schematics | 5 |
| Steps too lengthy | 10 |
| Needs further refining | 3 |

**What do you feel are problems with the LTTA?**

| | |
|---|---|
| Have to use TOs with them | 4 |
| Hard to follow | 17 |
| Unpractical for organizational level | 3 |
| Needs more diagrams | 6 |

**What do you feel are problems with the TO?**

| | |
|---|---|
| Need better troubleshooting charts | 8 |
| Hard to understand | 26 |
| Diagrams not clear | 3 |
| Requires too much experience | 8 |

## APPENDIX B

## GRAPHIC SUMMARIZATION OF STUDY RESULTS FOR MILITARY AIRLIFT COMMAND SUBJECTS

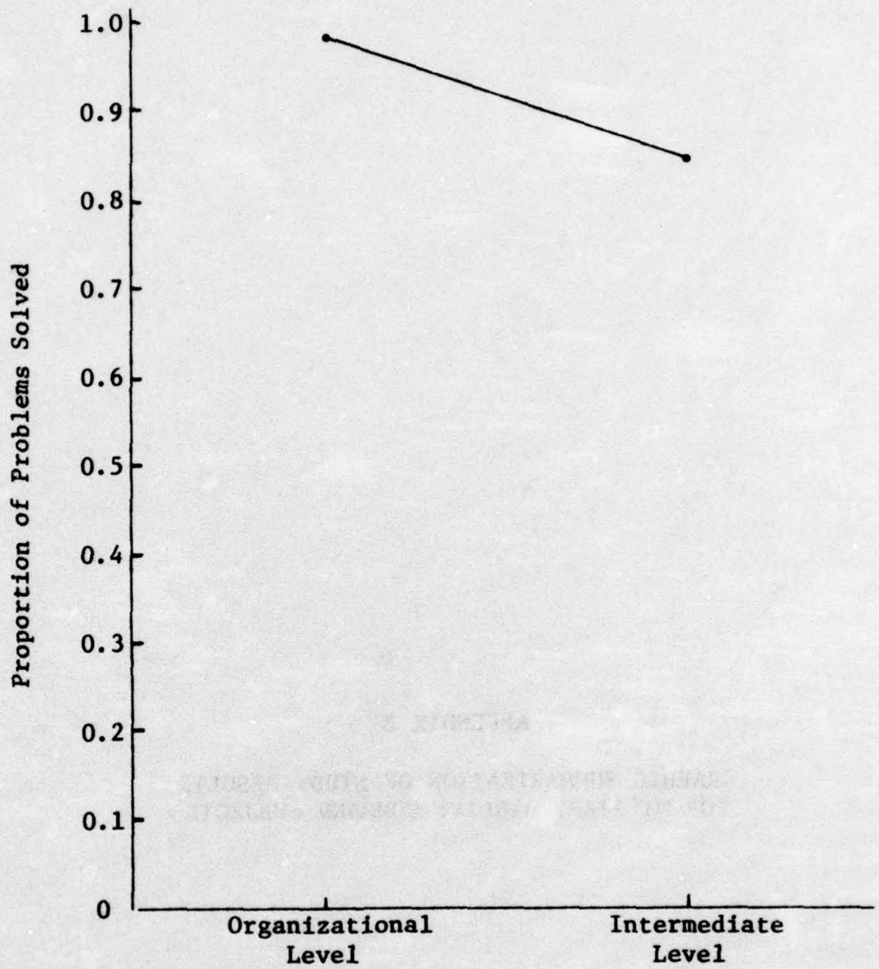


Figure B-1. Mean Proportion of Problems Solved by Level of Troubleshooting Maintenance, MAC Subjects

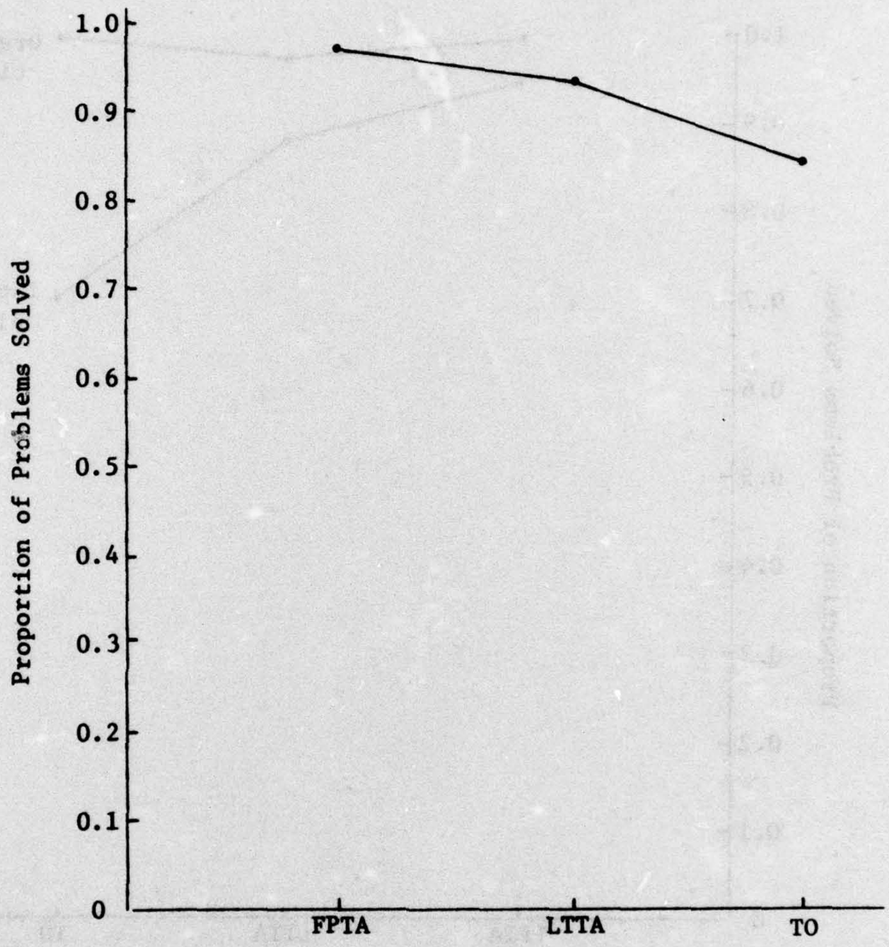


**Figure B-2. Mean Proportion of Problems Solved for Technical Documentation Type, MAC Subjects**

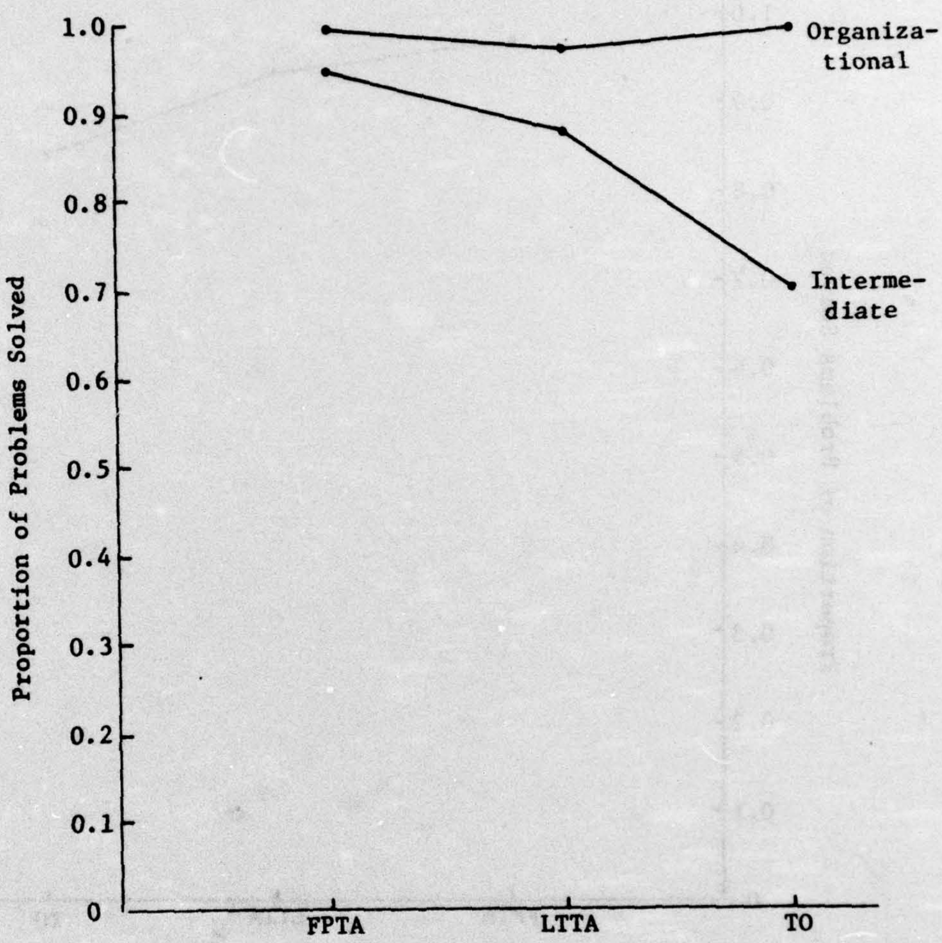


Figure B-3. Mean Proportion of Problems Solved for Type of Technical Documentation by Level of Trouble-shooting Maintenance, MAC Subjects

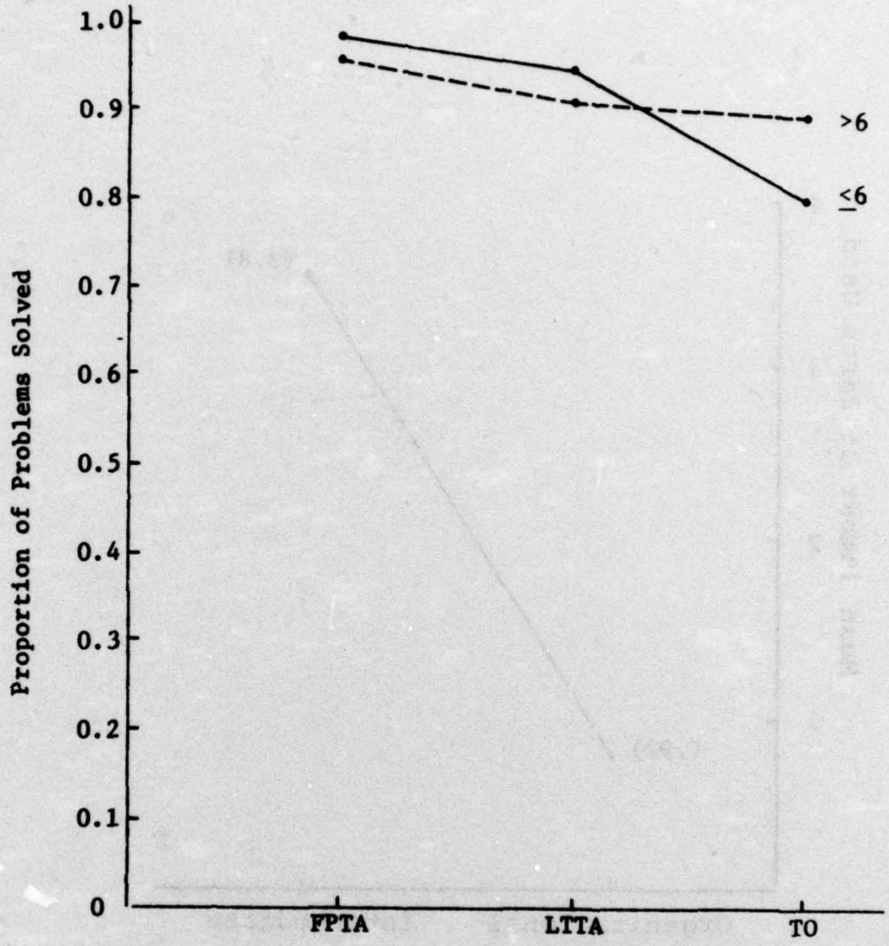


Figure B-4. Mean Proportion of Problems Solved for Technical Documentation Type by Experience Level (in months), MAC Subjects.

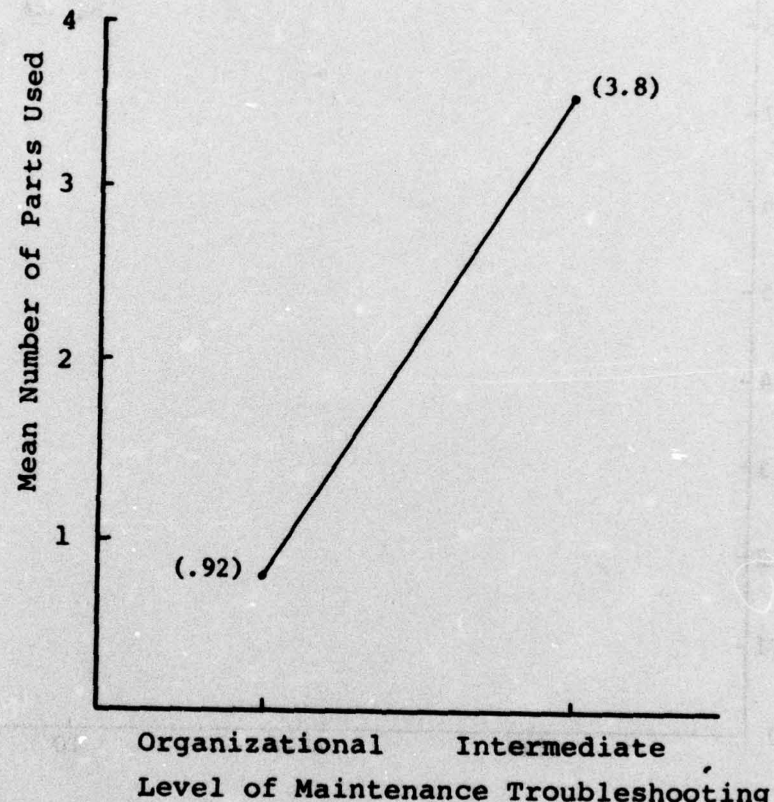


Figure B-5. Mean Number of Parts Used for Level of Maintenance Troubleshooting, MAC Subjects

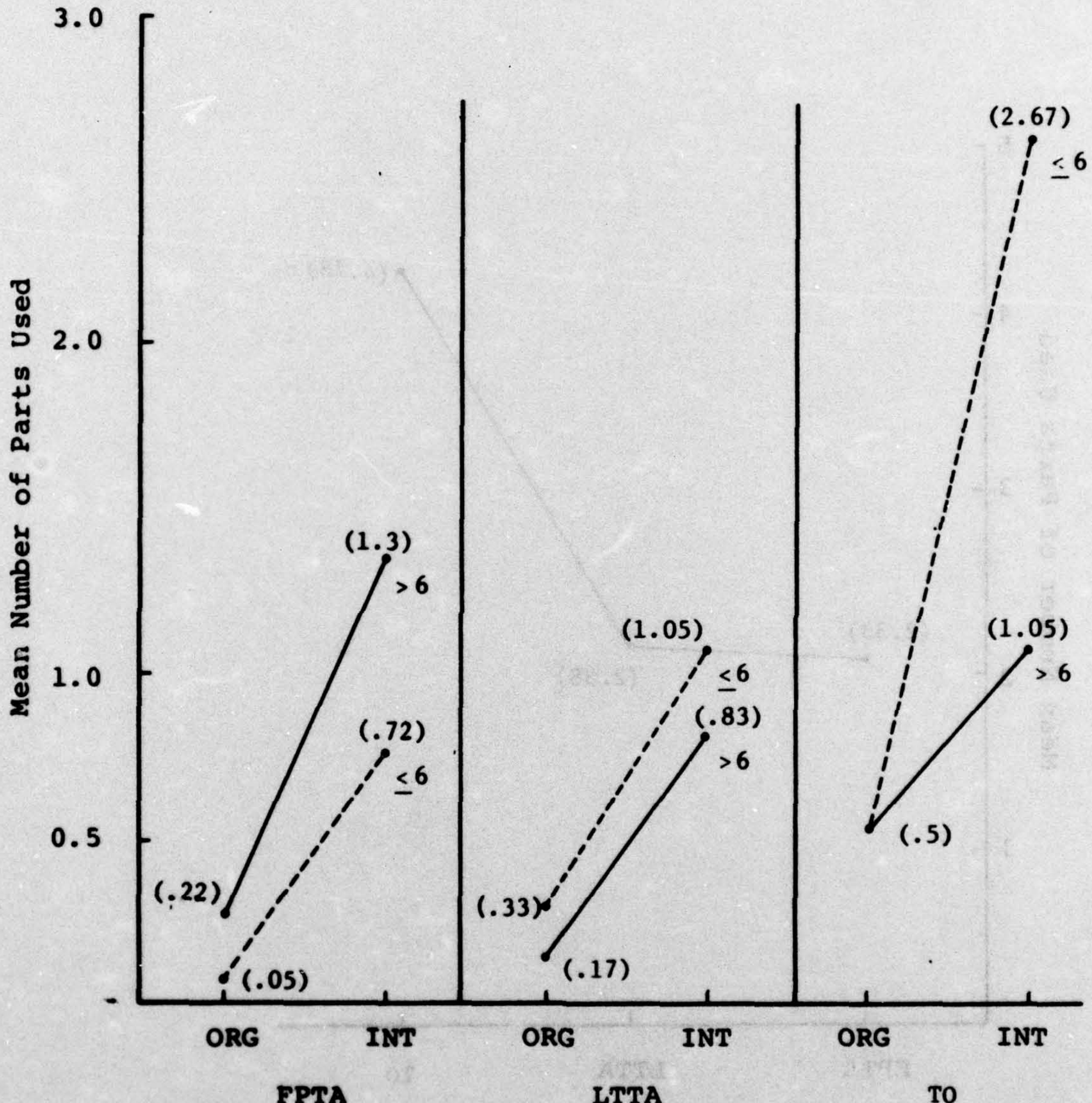


**Figure B-6. Mean Number of Parts Used for Experience Level in Months by Type of Technical Documentation by Level of Maintenance Troubleshooting, MAC Subjects.**

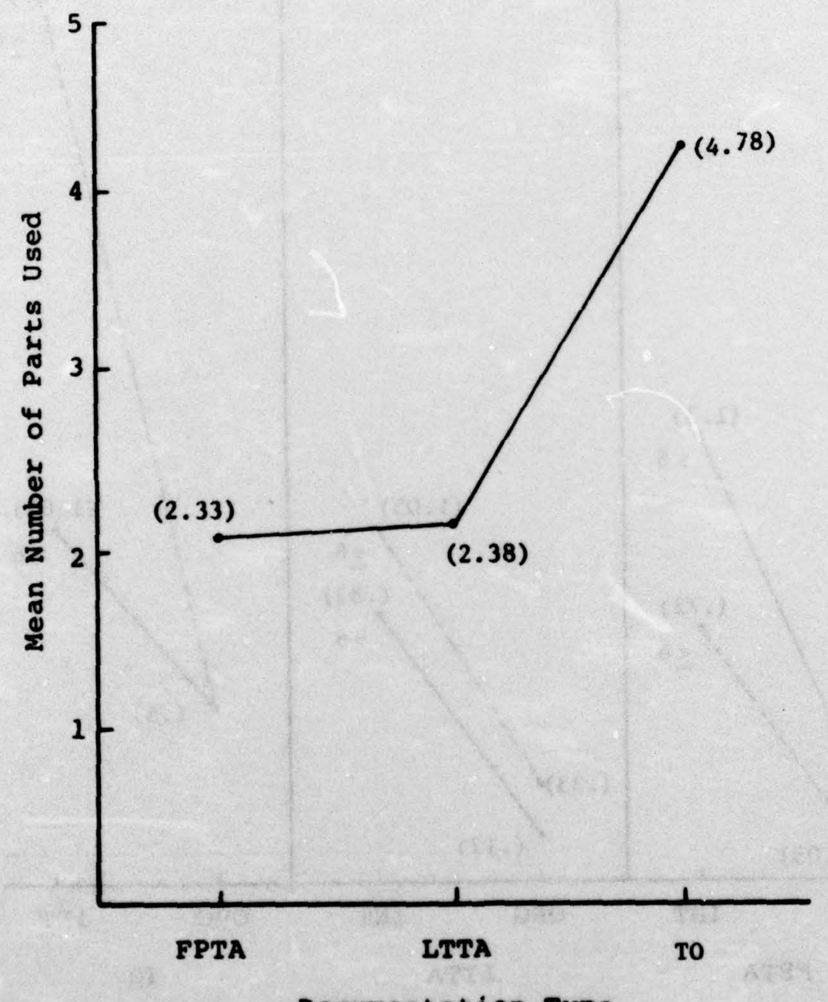


**Figure B-7. Mean Number of Parts Used for Type of Technical Documentation, MAC Subjects.**

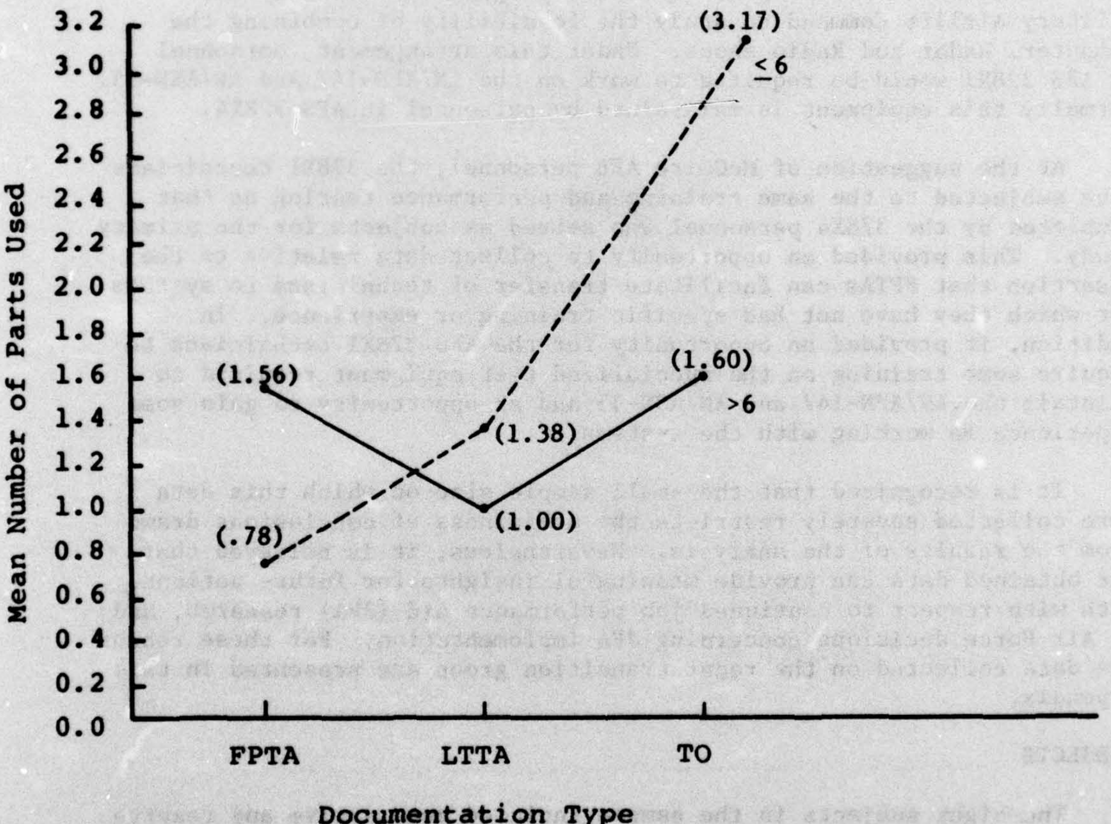


**Figure B-8. Mean Number of Parts Used for Type of Technical Documentation by Experience Level in Months, MAC Subjects.**

## APPENDIX C

## DATA COLLECTED ON A RESTRICTED SAMPLE OF RADAR TECHNICIANS TROUBLESHOOTING INERTIAL AND RADAR NAVIGATION SYSTEM PROBLEMS

### BACKGROUND

During the period of time that the field evaluation team was running subjects at McGuire AFB for data collection in the main experiment, data were also collected on eight technicians in AFS 328X1, Avionics Navigation Systems Specialist. These technicians were scheduled to participate in a test program conducted by the Military Airlift Command to study the feasibility of combining the Computer, Radar and Radio shops. Under this arrangement, personnel in AFS 328X1 would be required to work on the AN/APN-147 and AN/ASN-35. Normally this equipment is maintained by personnel in AFS 328X4.

At the suggestion of McGuire AFB personnel, the 328X1 technicians were subjected to the same training and performance testing as that completed by the 328X4 personnel who served as subjects for the primary study. This provided an opportunity to collect data relative to the assertion that FPTAs can facilitate transfer of technicians to systems for which they have not had specific training or experience. In addition, it provided an opportunity for the AFS 328X1 technicians to acquire some training on the specialized test equipment required to maintain the AN/APN-147 and AN/ASN-35 and an opportunity to gain some experience in working with the systems.

It is recognized that the small sample size on which this data were collected severely restricts the usefulness of conclusions drawn from the results of the analysis. Nevertheless, it is believed that the obtained data can provide meaningful insights for future actions, both with respect to continued job performance aid (JPA) research, and to Air Force decisions concerning JPA implementation. For these reasons the data collected on the radar transition group are presented in this appendix.

### SUBJECTS

The eight subjects in the sample included both active and reserve Air Force enlisted technicians who hold AFSC 328X1 (Avionics Navigation Systems Specialist). These eight subjects had little or no experience with the test systems. The levels of experience in electronic maintenance ranged less than six months to more than 15 years.

## PROCEDURE

The data collection procedures were identical to those utilized for collecting data from the MAC subjects for the primary study (see page 57).

## RESULTS

The results are presented in two formats. They are presented in the form of a proportional analysis for easy interpretation. This analysis is accompanied by a more thorough statistical analysis.

### Proportional Analysis

The proportion of problems solved using each type of data is presented in Figure C-1. From the figure it may be observed that all problems attempted with the TO as an aid were solved. Performance with the FPTA and LTTA was somewhat less effective with 90.9 and 88.9 percent of the problem correctly solved. In evaluating this observed difference, one should keep in mind that the number of problems attempted with each type of data is very small (32 problems, 11 with FPTA, 9 with LTTA, and 12 with the TO). Thus, there was only one problem missed with the FPTA and one with the LTTA.

At the intermediate level, the trend was reversed with use of the FPTA and LTTA resulting in the most effective performance. Use of the FPTA resulted in the best performance. Performance using the LTTA was lower than for the FPTA, but higher than performance with the TO.

The number of parts used by level of maintenance and type of technical documentation is portrayed in Figure C-2. These results should be interpreted with caution. One subject was responsible for 13 of the 39 parts used by the group. Eight of the 13 parts were used by this subject in solving problems at the intermediate level of maintenance using LTTA documentation. This usage rate was 2.7 times higher than any other subject and has an inordinate effect on the results obtained.

### Statistical Analysis

As the data on the eight radar transition subjects were collected within a repeated measures design, a total of 47 degrees of freedom was available for analysis. A summary table of the results of an analysis of variance for number of problems solved is presented as Table C-1. This analysis revealed that a statistically significant difference existed in performance for the two levels of maintenance troubleshooting. As discussed earlier, this difference was in line with expectations.

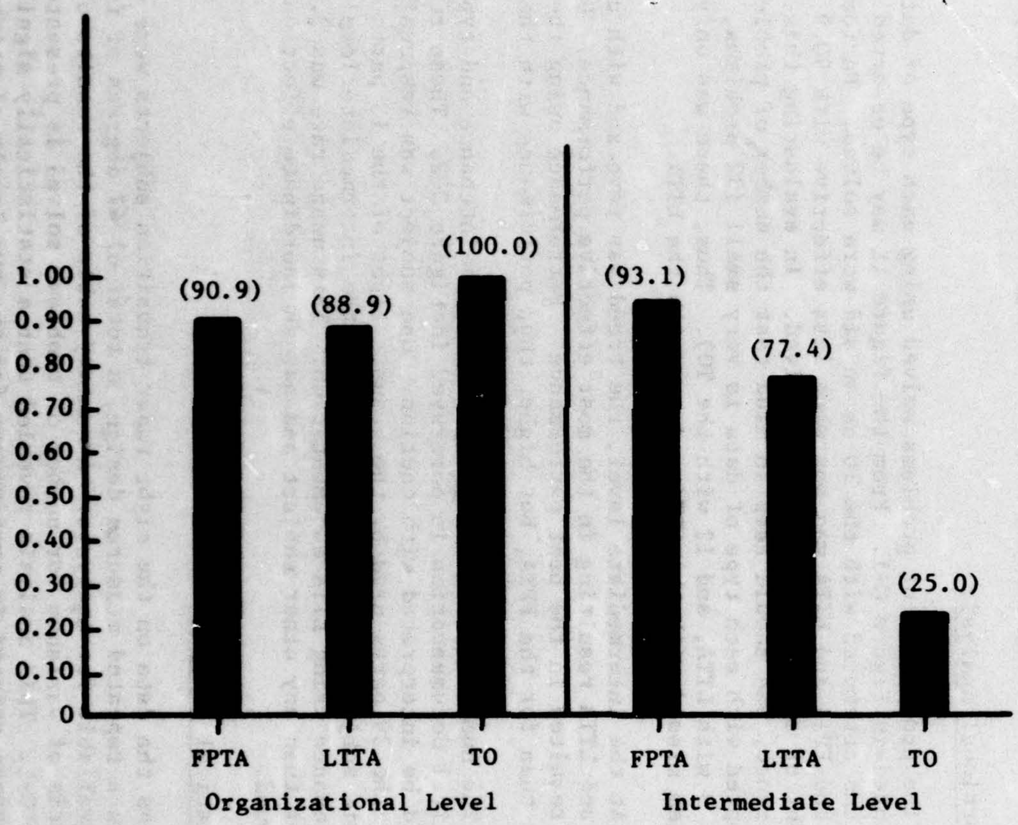


Figure C-1. Proportion of Problems Solved by Document Type and Level if Maintenance Troubleshooting for Radar Transition Group

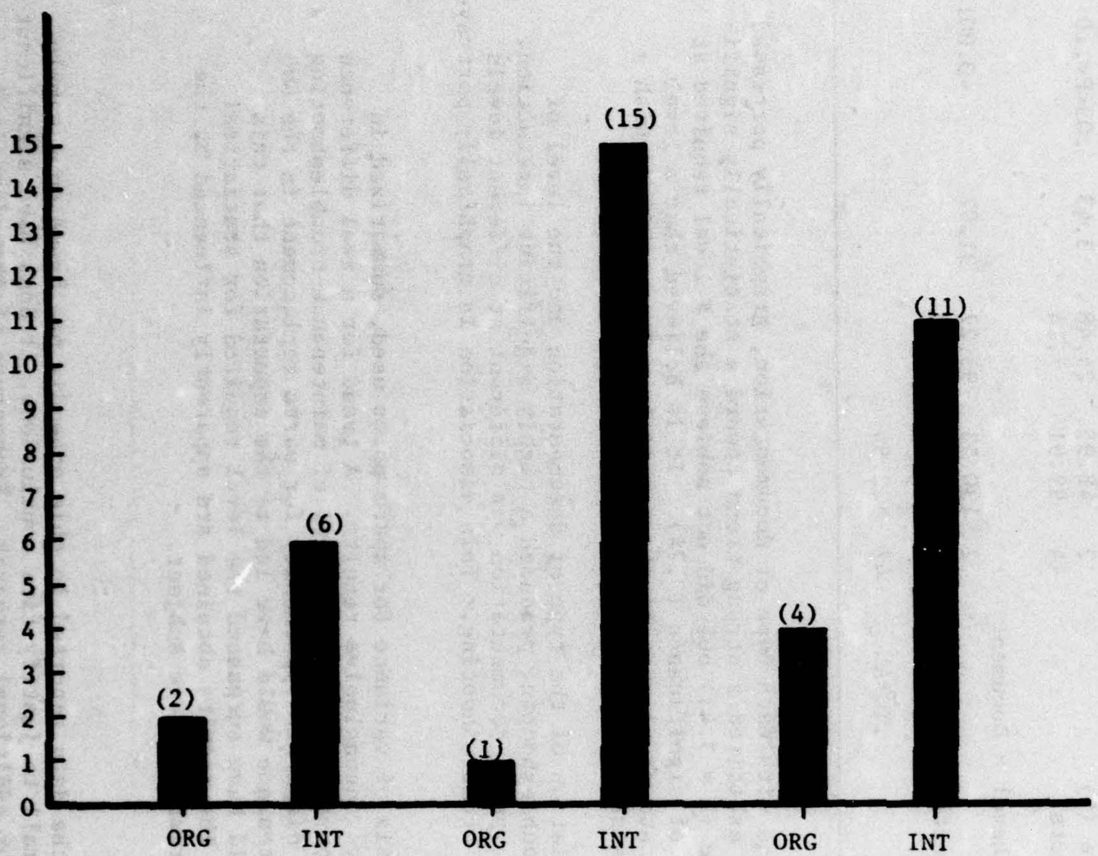


Figure C-2. Number of Spare Parts Used by Level of Maintenance and Type of Technical Documentation for the Radar Transition Group

TABLE C-1. ANALYSIS OF VARIANCE SUMMARY TABLE, RADAR TRANSITION GROUP, NUMBER OF PROBLEMS SOLVED, TRANSFORMED DATA

| | df | SS | MS | F | P |
|---|---|---|---|---|---|
| Subjects | 7 | 29.66 | | | |
| Maintenance Level (A) | 1 | 79.57 | 79.57 | 17.08 | <0.01 |
| A × Subjects | 7 | 32.65 | 4.66 | | |
| Document Type (B) | 2 | 48.95 | 24.48 | 3.43 | .05<P<.10 |
| B × Subjects | 14 | 99.91 | 7.14 | | |
| Maintenance Level × Document Type (A × B) | 2 | 190.53 | 95.27 | 31.97 | <0.001 |
| AB × Subjects | 14 | 41.67 | 2.98 | | |
| TOTAL | 47 | 522.94 | | | |

Performance with each type of documentation, graphically portrayed in Figure C-3, exhibited a strong trend toward a statistically significant difference (F = 3.43) but did not achieve the F level required at the 0.05 level of significance (3.74). It is believed that a level required for statistical significance would have been achieved with a larger sample size.

The association of the type of documentation and the level of maintenance troubleshooting produced a highly significant interaction. The effect of type of documentation was different at different levels of maintenance troubleshooting. This association is graphically portrayed in Figure C-4.

The analysis of variance for spare parts used, summarized in Table C-2 led to inconclusive results. A trend for a real difference in number of spare parts used by level of maintenance troubleshooting occurred. The disparate opportunity for parts replacement in the two levels of maintenance would have led to the expectation that this difference would have surpassed the level required for statistical significance. The results obtained are apparently influenced by the atypical performance of one subject.

## DISCUSSION

Although the data reported in this appendix are based on a sample which is too small to justify firm conclusions, it does have significant implications for additional research. Proponents of proceduralized troubleshooting have asserted that the use of this type of data can

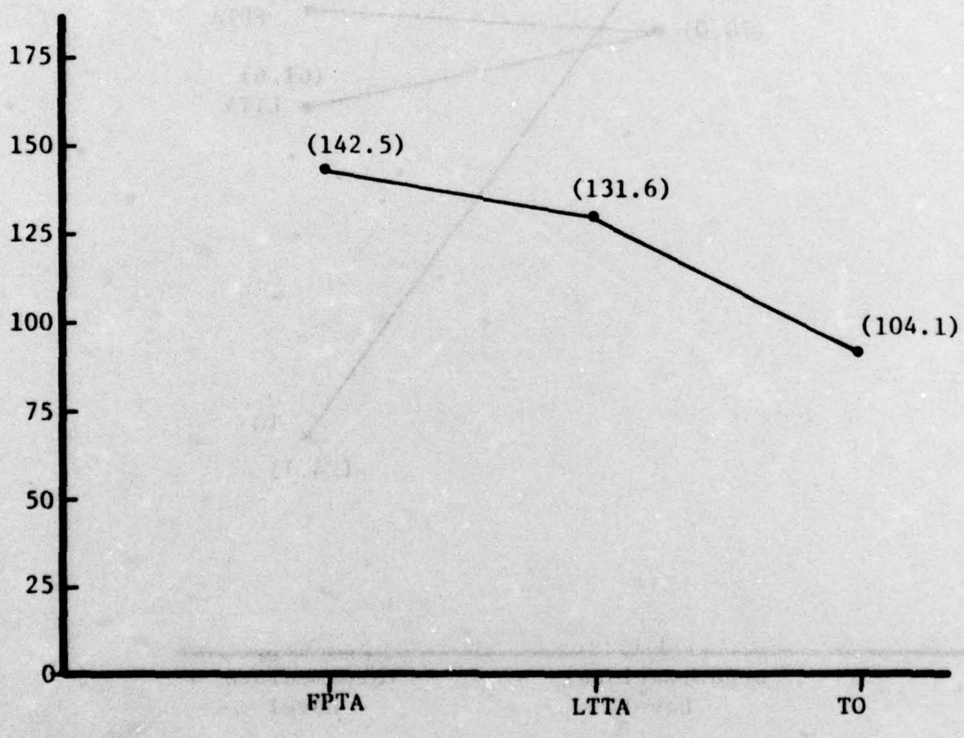


**Figure C-3. Number of Problems Solved (Transposed Data) for Radar Transition Group by Type of Documentation Used (A Score of 160 Is Possible)**

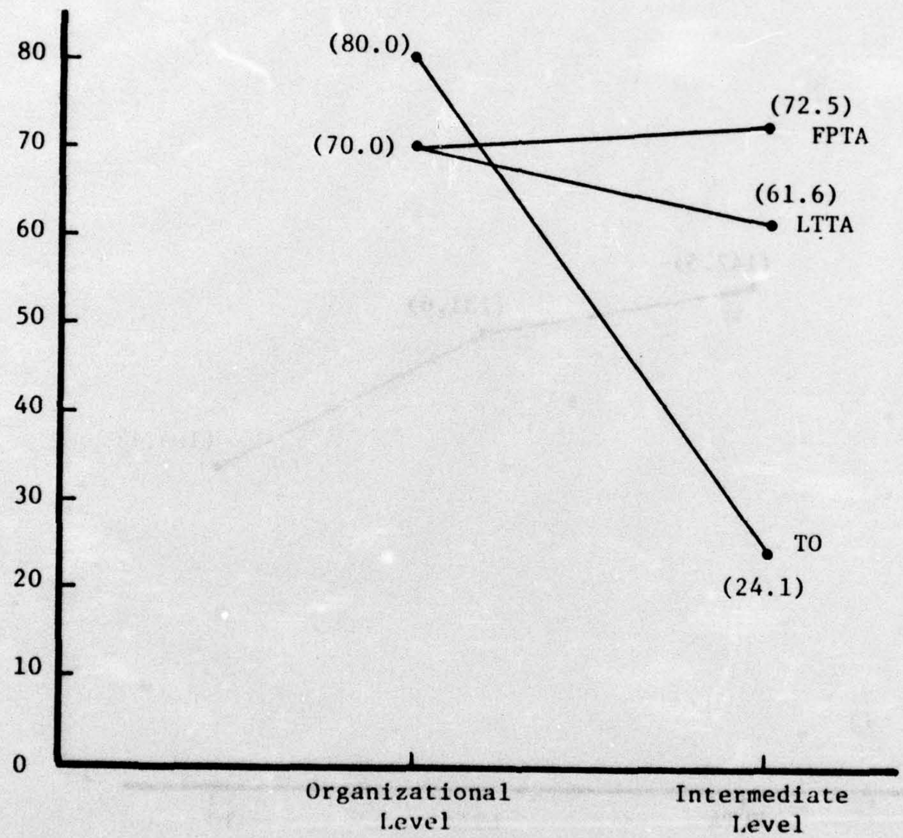


**Figure C-4. Problem Solving Performance (Transposed Data) for the Radar Transition Group by Level of Maintenance Troubleshooting and Type of Technical Documentation (A Score of 80 Is Possible)**

TABLE C-2. ANALYSIS OF VARIANCE SUMMARY TABLE, RADAR TRANSITION GROUP, NUMBER OF SPARE PARTS USED WITH FPTA, LTTA, AND TO

| | df | SS | MS | F | P |
|---|---|---|---|---|---|
| Subjects | 7 | 17.48 | | | |
| Maintenance Level (A) | 1 | 13.01 | 13.01 | 4.12 | .05<P<.10 |
| A × Subjects | 7 | 22.14 | 3.16 | | |
| Document Type (B) | 2 | 2.37 | 1.18 | <1 | |
| B × Subjects | 14 | 16.96 | 1.21 | | |
| Maintenance Level × Document Type (A × B) | 2 | 3.30 | 1.65 | <1 | |
| AB × Subjects | 14 | 20.05 | 1.43 | | |
| TOTAL | 47 | 95.31 | | | |

greatly facilitate the transition of electronic technicians to new systems. The observation that the eight technicians with no experience or training on the test systems were able to troubleshoot as well or better than technicians with training and experience on the systems using FPTAs, LTTAs, or TOs suggests that their assertion is valid. However, additional research is needed to verify these observations.



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